

"Report on Scientific Researches carried on during the Months of August, September, and October, 1871, in H.M. Surveying-ship 'Shearwater.'" By WILLIAM B. CARPENTER, LL.D., M.D., F.R.S. Received June 13, 1872.

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INTRODUCTION.

As it was understood that the requirements of the Public Service would not permit the employment, during any part of the last year (1871), of either the 'Porcupine' or the 'Lightning,' for the continuation of the Deep-sea Researches carried on by my Colleagues and myself in the three preceding summers, it was not deemed advisable by us that the Council of the Royal Society should be moved to make any application to the Admiralty in furtherance of this object. Early in June, however, I was informed by the Hydrographer that as the Surveying-ship 'Shearwater,' under the command of Capt. Nares, was about to proceed to the Mediterranean, and would not be required to enter on her work until the end of October, an opportunity would present itself for making further researches on the Gibraltar Current, in which, if so disposed, I should have the advantage of being associated with Capt. Nares; whilst, if inclined to proceed as far as Egypt, I might have an opportunity of prosecuting in the Eastern basin of the Mediterranean some of the Physical and Biological researches which I had carried out last year in the Western.

Although the results of the conjoint inquiries which had been made by Capt. Calver and myself during the 'Porcupine' Expedition of 1870 seemed to us to leave no reasonable doubt as to the existence of an outward Under-current in the Strait of Gibraltar, yet we both felt extremely desirous that the matter should be more thoroughly examined; for we were fully conscious that the proof could not be regarded as complete, until direct *mechanical* evidence should be obtained by the "current-drag" of the passage of Mediterranean water over the "ridge" or "marine watershed" between Capes Trafalgar and Spartel, which forms the proper boundary of the Mediterranean basin, the evidence we had obtained of such passage being *inferential*, and therefore open to objection. And as we saw, in addition, that the rate, perhaps even the direction, of this under-current was subject to variation under the influence of Winds and Tides, we felt that the

subject could not be fully elucidated without a far more prolonged and systematic study of its phenomena than it was in our power to carry out.

But, further, I had endeavoured to correlate the phenomena of the Gibraltar Current with those of the Bosphorus and Dardanelles Currents, and of the Baltic-Sound Current, under one general Physical Theory; and also to show that this Theory also applies to the doctrine of a General Oceanic *vertical* Circulation sustained by difference of Temperature. For whilst, in the case of Inland Seas, a disturbance alike of level and of equilibrium between their water and that of the outside Ocean will be produced either by excess of evaporation over the inflow of fresh water, or by an excess of the inflow of fresh water over evaporation, the like disturbance will be produced at the two extremes of each quadrant of the Earth along which there is a free communication between the Polar and Equatorial seas, by the opposite effects of Polar Cold and Equatorial Heat.

This view has been strongly opposed, however, on the one hand by Captain Spratt, and on the other by Mr. James Croll. The former has not merely affirmed* that this Physical Theory is altogether disproved, as regards the Bosphorus and Dardanelles Currents, by his own observations, but has called in question the validity of the evidence obtained by the inquiries of Capt. Calver and myself in regard to the Gibraltar Under-current, and has expressed his disbelief in the Under-current Theory altogether.—Mr. Croll, on the other hand, taking his stand upon what he regards as a well-established *datum* in regard to the gradient necessary to produce movement in water, considers that he has demonstrated the complete inadequacy of Thermal agency to maintain the General Circulation I advocate†.

The objections of a Surveying Officer of Capt. Spratt's ability and experience could not but be entitled to great respect; and I had therefore much satisfaction in availing myself of the opportunity afforded me by the Hydrographer, for cooperating with Capt. Nares in the re-investigation of the Gibraltar Currents, and for prosecuting such other scientific inquiries during the voyage to Alexandria as circumstances might admit.

The 'Shearwater' being specially fitted for the Surveying Service, only such arrangements could be made for Scientific research as were consistent with its requirements. And since it was not considered expedient to include *deep* Dredging in our *programme*, the following were the objects which I proposed to myself, in addition to the investigation of the Gibraltar Current:—

I. To ascertain whether *Serial* Temperature-soundings off the Coast of Portugal would justify the inference I had drawn, from the correlation of the *Bottom*-soundings taken in the previous year (Report for 1870, §§ 79, 80: Proc. Roy. Soc. vol. xix. p. 188), as to the existence of a

* Proceedings of the Royal Society, June 15, 1871 (vol. xix.).

† See his papers "On the Physical Cause of Ocean-currents" in the Philosophical Magazine for Oct. 1870 and Oct. 1871.

very distinct division between the *upper warm* and the *lower cold* stratum, in that portion of the Eastern Atlantic.

II. To ascertain whether any evidence would be furnished, by the relative Specific Gravities of the *surface*- and *bottom*-waters on the Atlantic slope of the "marine watershed" between Capes Spartel and Trafalgar, of the passage of Mediterranean water over that ridge.

III. To make a further Dredging-exploration of the comparatively shallow area between Sicily and the Coast of Africa,—part of it constituting the Skerki and Adventure Banks,—from which several specimens were obtained last year that proved of great interest.

IV. To make a sufficient number of deep Soundings in the Eastern Basin of the Mediterranean, to ascertain whether its water corresponds in Temperature and Density with that of the Western basin; and also, whether the deposit on its bottom is of the same character, and whether the water immediately above it is copiously charged, as in the Western basin, with very finely divided particles in suspension.

V. To ascertain, by analysis of the Gases of this bottom-water, whether the proportions of Oxygen, Nitrogen, and Carbonic acid correspond with those which had been found in the Northern Atlantic to be compatible with the presence of an abundant Fauna; or whether, as I suggested in my last year's Report (§ 103), the stagnation of the deeper part of the Mediterranean basin (in consequence of the want of Thermal Circulation) is attended with such an excess of Carbonic Acid and diminution of Oxygen, as is incompatible with the existence of Animal Life.

VI. To carry a series of Dredgings along the Northern Coast of Africa, eastward from Malta, in moderate depths, to ascertain how far its Fauna presents the same characters, and the same limitation to depths of between 150 and 200 fathoms, that it does in the corresponding part of the Western Basin.

With the view of enabling me to obtain the requisite assistance in carrying out the Zoological portion of the inquiry, and of meeting other scientific expenses, the Council of the Royal Society assigned a sum of £100 from the Government Grant; and this enabled me to secure, as on former occasions, the services of Mr. Laughrin as Dredger and Sifter.—A further sum of £50 was assigned to me from the Donation Fund, as a provision for the expenses of our return from Alexandria, the point at which we were to quit the 'Shearwater.'

The Admiralty having charged itself, as on former occasions, with the provision of Thermometers and Water-bottles, it was only requisite for me to provide the Apparatus needed for Gas-Analysis and for the accurate determination of Specific Gravities. As this last point was of special importance, and as I had found the use of a delicate Hydrometer on board ship, when there was even a trifling roll, to be attended with uncertainty, I thought it worth while to make trial of the method of taking Specific

Gravities by a graduated series of *bulbs*, adjusted to indicate differences of 0.1. On consulting Mr. Casella, I found him willing to undertake the construction of such a series, which should range from 1025.0 to 1030.0. These I have found to answer admirably, as the motion of a ship interferes much less with their performance than it does with that of a delicate Hydrometer.—I should strongly recommend that a similar series, graduated to every 0.2 (which is quite close enough for ordinary purposes), should be provided for general use at sea, instead of the Hydrometers at present furnished by the Meteorological Department. Every case of such bulbs should include a small Thermometer suited for taking the exact temperature of the water of which the Specific Gravity has to be ascertained, with a Table whereby the observed Specific Gravity may be reduced to a common standard—say 60°. In every observation, the Temperature should be carefully noted, and the requisite correction applied. I have strong reason to believe that the neglect of such correction has led to no small exaggeration of the differences between the Specific Gravities of the surface-water of the Ocean in different regions*. The record of observations ought either to state the result *as corrected*, or to state the Temperature at which each Sp. Gr. determination, if uncorrected, was made.—In the present Report all the Specific Gravities are reduced to the Standard of 60° Fahr.

As it is not probable that I shall again take a personal share in the work of Deep-sea Exploration, and as the present Report will therefore close the account of the Physical inquiries which I have been led to consider as my special department, I have thought it desirable to develop somewhat at length what I regard as the bearings of the results obtained by these inquiries upon the Doctrine of a General Oceanic Circulation sustained by difference of Temperature. This has involved a careful examination of the whole question of the Gulf-stream: as elucidated, on the one hand, by the careful and elaborate Surveys prosecuted near the American Coast under the able direction of the late Prof. Bache; and, on the other, by the Thermometric observations on the Surface-temperature of the Ocean, which have been recently correlated as regards the Atlantic by our own Hydrographic and Meteorological Departments, and as regards the Arctic Sea by Dr. Petermann. As no similarly comprehensive examination has been made, so far as I am aware, by any other scientific inquirer, and as the doctrine put forth on the subject by Mr. Croll is likely, if not thus scrutinized, to command the unquestioning assent of those who regard him as a high authority “on the subject of Oceanic Currents and their bearings on Geological questions”†, I venture to hope that the inclusion of its results as an Appendix to this Report will not be deemed inappropriate.

* I cannot but think that there must be some such fallacy in the statement of Dr. Rattray (Transact. of Linn. Soc. vol. xxvii. p. 272), that he encountered a range of Specific Gravity in the Ocean-water of the Pacific from 1023½ to 1029.

† Address of the President of the Geological Society, 1872, p. xxviii.

PART I.

TEMPERATURE-PHENOMENA OF THE ATLANTIC, IN RELATION TO
THOSE OF OTHER SEAS AND TO THE GENERAL OCEANIC CIR-
CULATION.

1. The first scientific work to which we applied ourselves was the obtaining, on the 16th of August, a deep Temperature-sounding in Lat. $41^{\circ} 9' N.$ and Long. $10^{\circ} 2' E.$,—about 60 miles to the west of Oporto. The depth here struck was no less than 2100 fathoms; but unfortunately the line parted in reeling-in, and we lost two thermometers and a water-bottle. This incident was greatly to be regretted, as the results of Serial Soundings at this depth would have been of peculiar interest.—Circumstances were unfavourable, however, to the renewal of the attempt in this locality.

2. On the 17th we took three Soundings nearer the Coast of Portugal; the first two in Lat. $38^{\circ} 20\frac{1}{2}' N.$ and Long. $9^{\circ} 23' W.$, which, with a surface-temperature of 66° , gave a bottom-temperature of $54^{\circ} 5$ at 570 fathoms, and 56° at 600 fathoms; while the third, in Lat. $38^{\circ} 13' N.$ and $9^{\circ} 21' W.$, gave 53° in 590 fathoms. These temperatures were higher by 5° or more than those which were obtained last year, nearly in the same locality, at corresponding depths (see Report for 1870, § 79); and I cannot account for this elevation in any other way, than by supposing that as we know the bottom along this part of the coast to be very rocky and irregular, with many "holes," the area within which the higher temperatures were found may have been cut off, as regards its deeper stratum, from the basin of the Atlantic,—just in the same manner as the deeper portion of the Sulu Sea appears to be cut off from the China Sea (§ 12).

	Atlantic.		Mediterranean.	
	° Fahr.	Below surface.	° Fahr.	Below surface.
Surface	68	°	69.5	°
10 fathoms	68.5	+ 0.5	59	—10.5
20 „	62	— 6	57.5	—12
30 „	61	— 7	56.5	—13
40 „	59.5	— 8.5	55.7	—13.8
50 „	59.5	— 8.5	55.3	—14.2
60 „	59	— 9		
70 „	58.8	— 9.2		
80 „	58.5	— 9.5		
90 „	58	—10		
100 „	57.7	—10.3	54.7	—14.8

3. On the 19th of August we took another deep Sounding in Lat. $36^{\circ} 47' N.$ and Long. $9^{\circ} 39' W.$,—about 60 miles to the S.W. of Cape St. Vincent. The surface-temperature being here 68° , the temperature of the bottom at 1560 fathoms was $37\frac{1}{2}^{\circ}$. A series of Temperature-soundings at intervals of 10 fathoms down to 100 fathoms having been then taken by Capt. Nares at my request, the results given in the Table, p. 539, were obtained, which it may be well to compare with the temperatures obtained at corresponding depths, and nearly under the same latitude, within the Mediterranean (Report for 1870, § 87, Series II.).

4. The continuity of the surface-temperature through the uppermost ten fathoms' stratum, with even a slight *increase*, was a phenomenon which I have not myself met with in any other instance, the temperature at 10 fathoms' depth being generally at least 3 degrees *below* that of the surface. But Capt. Chimmo, in his "Soundings and Temperatures in the Gulf-stream" (Proceedings of the Royal Geographical Society, vol. xv. 1871, p. 99) states that out of 45 carefully obtained observations between Halifax and the Mid-Atlantic, 26 gave a temperature at 12 fathoms *warmer* than the surface,—sometimes as much as $1\frac{1}{2}^{\circ}$,—10 colder, and 9 of the same temperature; whilst he further states that in the Pacific, off the Isalcos Mountains on the west coast of America, the temperature has been found not less than 10° or 11° higher at 12 or 15 feet below the surface than at the surface. This he presumes to be due to excessive evaporation, as he has often there found the difference between the wet- and the dry-bulb thermometer to be 9° , and on one occasion 11° . From this it seems probable that the marked differences observable between the rates of descent of the thermometers in the subsurface-stratum are partly referable to the *hygrometric* condition and movement of the air above, which will have an influence even more potent than Temperature *per se* upon the rate of evaporation from the surface.

5. Having been led to believe, by the bottom-soundings taken last year, that the temperature of the upper stratum of the Atlantic from 100 fathoms down to the "stratum of intermixture" would here fall pretty regularly to about 50° at 700 fathoms, I did not think it needful that time should be spent in carrying Serial soundings continuously downward, if the temperature at that depth should be found to accord with my expectations; and this it did in a very satisfactory manner, the thermometers sent down to 700 fathoms giving $50^{\circ}\cdot5$. I therefore requested Capt. Nares to take successive temperature-soundings from 700 fathoms downwards, at intervals of 100 fathoms; and these also gave the result I had anticipated, the thermometer falling to 46° at 800 fathoms, to 42° at 900 fathoms, and to 38° at 1000 fathoms. From 1000 fathoms to the bottom at 1560 fathoms, the further reduction was only from 38° to $37\frac{1}{2}^{\circ}$.

6. Thus, then, this set of *Serial* soundings fully confirmed the deduction I had ventured to draw last year (Report for 1870, § 81), from the

bottom-soundings taken in the 'Porcupine' along the coast of Spain and Portugal, as to the well-marked distinction between the *upper warm stratum* and the *lower cold stratum*, with a *stratum of intermixture* between the two. For whilst the reduction of temperature beneath the superheated stratum of the surface was only from $57^{\circ}7$ at 100 fathoms to $50^{\circ}5$ at 700 fathoms—that is to say, $7^{\circ}2$ in 600 fathoms, or at the rate of $1^{\circ}2$ per 100 fathoms,—the reduction between 700 fathoms and 1000 fathoms was $12^{\circ}5$, or at the rate of nearly $4^{\circ}2$ per 100 fathoms; while the whole mass of the deeper water from 1000 fathoms down to the bottom at 1560 fathoms was found to have a temperature between 38° and $37\frac{1}{2}^{\circ}$.

7. The significance of these facts becomes most apparent when they are graphically contrasted (as in Plate III.) with the temperature-phenomena of the Mediterranean under nearly the same parallel; for, as was proved by the 'Porcupine' Temperature-soundings of 1870 in the Western basin, the temperature from 100 fathoms (at which depth the influence of direct insolation appeared to cease) down to the bottom at 1400 or 1500 fathoms is *uniform throughout**, namely about $54\frac{1}{2}^{\circ}$. It is clear, therefore, (1) that depth *per se* does not give rise to any change in the temperature of sea-water occupying a basin which has only a superficial connexion with the great Ocean-system; and consequently (2) that the diversities of temperature shown in the different strata of the Atlantic must depend upon their derivation from different sources.

8. Now with regard to the *upper stratum* lying between 100 and 700 fathoms, there is no evidence of its derivation from any Southern source; on the contrary, the Temperatures taken at 200 and 400 fathoms, in the recent voyage of the New York School-ship 'Mercury' from Sierra Leone to Barbadoes (the Report of which has been kindly transmitted to me by Prof. Draper), indicate that below the stratum superheated by direct insolation, the temperature is even *lower* between the Tropics than it is in this more northern portion of the Atlantic area. For the average of nine observations at 200 fathoms, taken where the depth of the Oceanic basin was 1000 fathoms or more, was almost exactly 52° , the range being only between 54° and 50° ; and the temperature at 400 fathoms, about 350 miles east of Barbadoes, was only 47° .

9. If this last fact should be confirmed by further inquiries, it will furnish a powerful argument in support of the doctrine of a *vertical Oceanic Circulation* which I have repeatedly advocated; since it is obvious that as it will be in the Intertropical area that the cold bottom-water will be most rapidly brought up to the surface (Report for 1870, § 127), the temperature of the stratum not yet within reach of direct insolation might

* This uniformity had been previously observed by Capt. Spratt; although, from the want of "protection" of his Thermometers, he had assigned too high a temperature to the deeper stratum of the Mediterranean basin.

be expected to be *lower* than it is in the Temperate area. And it is a very curious confirmation of this view, that three of the temperatures taken in the 'Mercury' at 200 fathoms, which ranged several degrees higher than the average,—viz. 60° , 60° , and 58° ,—were over a bottom (between Sierra Leone and the Cape-Verde Islands) of which the depth ranged only from 290 to 680 fathoms; though to the south as well as to the north of these stations, where the depths were respectively 1000 and 1100 fathoms, the temperatures at 200 fathoms were 53° and 54° . For if bottom-water, in its gradual rise towards the surface, starts from great depths at an almost glacial temperature, it will obviously be much colder, until it has come under the direct influence of insolation, than if it has started from a shallower bottom at a temperature of (say) 45° .

10. But whilst the Temperature of the *upper* stratum in our Atlantic sounding does not give any definite indication of the derivation of its water from any remote source, the case is very different in regard to the temperature of the stratum *below* 1000 fathoms. For I am at a loss to conceive how the rapid fall in the Thermometer between 700 and 1000 fathoms, and the depression of Temperature below 38° which exhibits itself in this Sounding down to 1560 fathoms, and in the Soundings taken by the 'Porcupine' in 1869 from 1000 fathoms down to 2090 and 2435 fathoms, are to be accounted for, unless on the hypothesis that the temperature of this stratum has been reduced by the flow of glacial water from the Polar area towards the Equatorial. For it seems clear that any mass of sea-water which remains long enough on the same bottom, *must* come to acquire a temperature *at least as high* as that of the bottom, unless cooled below this either by the action of Atmospheric cold on its surface, or by the intrusion of colder water from some extraneous source. Now, in the case of the Western basin of the Mediterranean, the *uniform temperature* ($54\frac{1}{2}^{\circ}$) of the whole stratum beneath 100 fathoms agrees so well on the one hand with the *mean temperature of the crust of the earth* in that region (Report for 1870, § 89), and on the other with the *lowest winter temperature* of its surface*,—while the comparative shallowness of the "ridge" between Capes Spartel and Trafalgar so effectually prevents the admission of any considerable body of water of a temperature below $54\frac{1}{2}^{\circ}$ from the depths of the Atlantic outside,—that we may fairly assume that temperature to be *the normal of the Latitude*. And since, in the Eastern Atlantic outside the Strait, the whole mass of water below 1000 fathoms has a temperature *from sixteen to eighteen degrees below this normal*, which cannot be attributed to the action of surface-cold in the locality itself, the inference seems irresistible that this depression must be produced and maintained by the *convection of cold* from the Polar towards the

* See the Memoir of M. Aimé on the Temperature of the Mediterranean, in 'Ann. de Chim. et de Phys.' for 1845.

Equatorial area,—the low conducting-power of water altogether forbidding the idea that such a permanent depression can be sustained by *lateral conduction* from the Polar area against the warming influence of the bottom beneath and of the air above. And if this be admitted as probably true with respect to the Temperate area to which my own inquiries have been limited, with how much more force does the same argument apply to the Intertropical region, where, with a surface-temperature rarely, if ever, falling below 75° , we find a temperature of 47° at so small a depth as 400 fathoms, and a *bottom*-temperature but little above the freezing-point of fresh water—the “protected” Thermometers used by Commander Chimmo in the Indian Ocean having registered $35^{\circ}2$ at 1806 fathoms, $33^{\circ}6$ at 2306 fathoms, and 32° at 2656 fathoms, in Lat. $3^{\circ} 18\frac{1}{2}'$ S., and Long. $95^{\circ} 39'$ E. (See p. 590.)

11. If any confirmation of this view be thought requisite, it is supplied by a similar comparison of the Temperatures of two other Inland Seas with those of the Oceanic Basins with which they communicate. The Red Sea, like the Mediterranean, is entirely cut off from communication with the deeper and colder stratum of the Arabian Gulf, with which its surface-layer communicates through the shallow Strait of Babelmandeb. Whilst the lowest (February) temperature observed in that surface-layer, even in the northernmost extension of the Red Sea known as the Gulf of Suez, is 71° (as I learn from Capt. Nares, who has been recently engaged in its survey), that temperature is there carried uniformly down to the bottom at 450 fathoms; and it may hence be pretty certainly affirmed that no lower temperature than this will be found in the southern portion of the Red Sea, even on a bottom exceeding 1000 fathoms in depth, since the lowest surface-temperature of that portion is probably never less than 75° . Yet in the Arabian Gulf the temperature at a depth of 2000 fathoms is certainly *not above*, and is very probably *below* $36^{\circ}5$ *.

12. The like contrast is shown by the Temperature-soundings of Commander Chimmo (which have been kindly communicated to me by the Hydrographer), between the deep temperature of the Sulu Sea,—a small area between the north-eastern portion of Borneo and Mindanao,—and that of the China Sea. The former, though not ostensibly an inland sea, being but very partially surrounded by land, is so shut in by reefs and shoals, as to have only a very superficial and limited communication either with the China or with the Celbes Sea. Notwithstanding this enclosure, its depth is very great, ranging to 1778 fathoms; and its Temperature-phenomena present *exactly the same contrast* with those of the China Sea that the temperature-phenomena of the Mediterranean present when compared with those of the Eastern Atlantic, as will be seen in the Table in the next page.

* See “Report” for 1869, § 120.

	Sulu Sea.	China Sea.
Surface	83°	84°
30 fathoms .....	....	77
40 " .....	....	74
50 to 80 fathoms .....	....	71
100 fathoms	64·5	
120 " .....	....	62
150 " .....	....	56
200 "	56·2	51
250 " .....	....	49
308 "	51·5	
416 " .....	....	41
500 to 1778 fathoms	50	
550 to 1546 " .....	....	37

Thus it appears that with surface-temperatures almost exactly identical, and with a rate of descent through the first 100 fathoms which seems nearly the same, there is a most marked difference beneath. For whilst in the Sulu Sea the thermometer only falls to $56^{\circ}\cdot 2$ at 200 fathoms, to $51\frac{1}{2}^{\circ}$ at 308 fathoms, and to 50° at 500 fathoms, and the temperature is uniform from that point down to the bottom at 1778 fathoms, it descends rapidly in the China Sea to 51° at 200 fathoms, thence to 41° at 416 fathoms, and thence to 37° at 550 fathoms, at which point it remains stationary down to the bottom at 1546 fathoms. This difference is attributed by Capt. Chimmo—in my opinion with adequate reason—to the exclusion from the Sulu Sea of the deep Polar flow which lowers the temperature of the China Sea. That the uniform temperature of its *deep* water from 500 fathoms downwards is *lower* by 4° or 5° than that of the Mediterranean, notwithstanding that the temperature of its *superficial* stratum is considerably *higher*, can be easily accounted for on the very probable supposition, that there are passages between the reefs and islands which admit water of a temperature below 50° from the outside Sea; in fact we might almost certainly fix the *minimum* depth of such passages as about 250 fathoms. (See also the Addenda in pp. 589, 590). These contrasts—graphically represented in Plate III. (in which the *dotted* lines show the temperatures of the *inland* Seas, and the *continuous* lines the temperatures of the adjacent *Oceans*)—are readily explicable on the doctrine of an underflow of Polar water towards the Equator; and how they are otherwise to be accounted for, I am myself at a loss to conceive.

13. This *underflow* involves, as its necessary complement, a movement of the *upper* stratum, bearing with it the warmth of Temperate seas, towards the Pole; and of such a movement very cogent evidence is afforded by the following comparison of the Temperatures obtained in the 'Porcupine' Expeditions of 1869 and 1870, between 100 and 500 fathoms

depth, at four Stations having an extreme range of 23° of Latitude,—the *first* of these stations being off the coast of Portugal, the *second* about 240 miles to the S.W. of Cork, the *third* about 100 miles south of Rockall, and the *fourth* about 120 miles to the N.W. of Stornoway:—

	I. N. Lat. $36\frac{1}{2}^{\circ}$.	II. N. Lat. 49° .	III. N. Lat. 56° .	IV. N. Lat. $59\frac{1}{2}^{\circ}$.	Extreme difference between I. and IV.
Air	70°	63°	58°	54°	16°
Surface	68	62·6	57·3	52·6	15·4
100 fathoms	57·7	51·1	48·5	47·3	10·4
200 „	55	50·5	48	46·8	8·2
300 „	53	49·6	47·8	46·6	6·4
400 „	52	48·5	47·5	46·1	5·9
500 „	51·5	47·4	45·8	45·1	6·4
Difference between 100 and 500. . }	6·2	3·7	2·7	2·1	

Now in the first place it is to be noted how closely the Temperature of the *surface* of the Sea corresponds with that of the Air; the reduction of both, in passing northwards, being at almost precisely the same rate, and the extreme differences being nearly identical. Next it will be observed that these differences diminish in amount from above downwards, showing that as the influence of insolation (which is for the most part restricted to 100 fathoms' depth) is lost, there is an increasing tendency to uniformity of temperature. This influence extends the deepest, as might be expected, at the southernmost station; the range between 100 and 500 fathoms being there $6^{\circ}2$, whilst at the northernmost station it is only $2^{\circ}1$. But while the temperatures at Station I. from 100 to 500 fathoms so nearly correspond with the uniform temperature of the Mediterranean between the same depths as to justify our assuming this to be nearly the normal of the Latitude, but little modified by the convection either of heat or of cold from any extraneous source (§ 8), the temperature at Station IV. of the whole stratum of water between 100 and 500 fathoms is so much *above the normal of its Latitude* as clearly to depend upon a *translation* of warm water from a Southern area. And when we compare these extremes with the intermediate temperatures of corresponding strata at Stations II. and III., we see how *regularly gradational* is the transition; the rate of diminution being about *half* a degree (Fahr.) for every degree of Latitude at 100 fathoms, and coming down to little more than a *quarter* of a degree between 300 and 500 fathoms. The inference seems unavoidable, that the entire stratum of water down to at least 500 fathoms has flowed northwards to the parallel of $59\frac{1}{2}^{\circ}$ from some lower parallel, losing heat in its way by imparting it to the air above; that loss of heat being chiefly shown in

the *superficial* layer, in which it is more than twice as great as it is beneath.

14. Now, that there *is* a slow N.E. movement of the upper stratum of the water of this part of the North Atlantic, is affirmed by Admiral Irminger as the result of the careful discussion he has made of the reckonings kept by ships of the Danish Navy in their passages to and from Iceland and Greenland; the rate of that movement being estimated by him at from 0·8 to 4·7 miles per day*. On the other hand, that beneath this N.E. flow there is, in what I propose to call the "Lightning Channel," between the Shetland and the Faroe Islands†, a S.W. flow of glacial water which can scarcely have any other than a Polar source, appears to me to be no less unmistakably proved by the observations recorded in my Reports for 1868 and 1869. For if this glacial stream were not continually being renewed from its Polar source, it could not retain its temperature of from 32° to 29½° against the warmth imparted to it not merely by the crust of the Earth beneath, but by the warm stream coming up against it. And a further significant indication of its movement is afforded by the comparison of the two sets of *Serial Soundings* taken in the Cold Area (Report for 1869, Proc. Roy. Soc. vol. xviii. p. 456); namely, No. 64 extending to a depth of 640 fathoms, and No. 52 at which the depth was only 384. For although the latter Station was a degree to the *southward* of the former, and its surface-temperature was 2°·4 higher, the glacial stratum was sooner reached; the stratum from 300 fathoms to the bottom at 384 having a temperature between 30°·8 and 30°·6, which was only met with in No. 64 over its deeper bottom at a depth of from 400 to 450 fathoms. This case, therefore, seems precisely parallel to the creeping of Polar water up the sides and over the ridges of submarine hills, of which the U.S. Coast Surveyors have obtained distinct evidence in the Florida Channel (§§ 129–133); and it does not seem explicable upon any other hypothesis, than that of a *flow* of the colder stratum, which, if left at rest, would gravitate to the deeper part of the channel.

15. Proceeding still further North, we find this glacial stratum lying nearer and nearer to the surface the nearer we approach the Polar ice-barrier. This appears very clearly from the Temperature-soundings which have been recently taken in the neighbourhood of Spitzbergen by M. Charles Martins and by MM. Payer and Weyprecht; these having effectually disposed of the notion that the deeper water is warmer than the superficial, so that the Thermometer *rises* as it descends. That such a rise not unfrequently presents itself to a limited extent is indubitable, the observations

* Proceedings of the Royal Geographical Society, May 10, 1869.

† The discovery of the remarkable contrast between the bottom-temperatures met with at like depths in adjacent areas of this Channel having been made by the Temperature-soundings taken in the 'Lightning' Expedition of 1868, it seems not inappropriate to give it the name of that Ship; more especially as the 'Lightning' has a further historical interest, as one of the first two steam-vessels built in 1825 for the British Navy

of M. Charles Martins on this point having confirmed those formerly made by Scoresby off the coast of Greenland, in indicating a temperature *above* 32° at 40 fathoms, when the temperature of the surface is *below* 32° . This is easily accounted for by the *inferior salinity* of the cold surface-stratum, the reduction of its temperature and of its salinity being alike due to the melting of ice. For if the ice be that of Icebergs formed as Glaciers on land, the water into which it dissolves will be entirely fresh; whilst if it has been formed by the freezing of sea-water, so large a part of its salt will have been left out in the act of congelation, that the product of its liquefaction will be of comparatively low Specific Gravity; and thus Sea-water at or even below 32° may float upon water some degrees warmer than itself. That this is really the explanation of many cases of this kind, seems probable from the fact, which I have learned from Capt. Toynbee (of the Meteorological Department), that when our American Packet-ships, in crossing the Atlantic, meet with a sudden depression of surface-temperature, they find the Specific Gravity also of the surface-water to be sensibly lessened; both results being pretty certainly due to the melting of icebergs borne southwards by the Arctic Current.—But the strata of Ocean-water do not always arrange themselves in accordance with their relative Specific Gravities and Temperatures. Two currents may meet, as on the Agulhas Bank, in such a manner that the inclination of the Sea-bed throws up the colder one nearer to the surface than the warmer; and the former may maintain this superiority of position as long as its force of translation lasts. This agency was doubtless operative in the following remarkable case cited by Dr. Petermann:—"Lieut. Rogers, in 1855, found "in the Asiatic part of the Arctic Ocean a warm surface-current with water "of low Specific Gravity; beneath it a cold current; and then, again, a warm "current of heavier water; and all these strata running in opposite directions." I am informed by Mr. Leigh Smith, who last summer penetrated to the N.E. of Spitzbergen, that he has encountered a similar succession.—Cases of this kind, however, do not invalidate the general fact, that the glacial stratum in Polar Regions extends from less than 50 fathoms below the surface to the bottom, however deep. Thus Scoresby found the temperature at about 120 fathoms to be 29° , when it was 34° at the surface. Sir Edward Parry found the surface-temperature off Spitzbergen to vary from 31° to 28° , and the bottom-temperature at depths down to 100 fathoms to vary from 30° to 28° . Sir John Ross found the temperature in Lat. $72^{\circ} 33' N.$ and Long. $73^{\circ} 7' W.$ to be 35° at the surface, and to decrease gradually to $28\frac{1}{4}^{\circ}$ at a depth of 1000 fathoms. And the recent observations of M. Chas. Martins have shown that from 40 fathoms downwards the temperature constantly undergoes reduction, until the thermometer stands below 29° *. This is confirmed by the still more recent observations of MM. Weyprecht and Payer, which further show that the stratum above 32° becomes thinner as it flows northwards:—

* The foregoing Temperatures are stated on the authority of Mr. Prestwich. See his Presidential Address for 1871, in the Quart. Journ. of the Geological Society, p. lix.

Lat. 72° 30' N.		Lat. 76° 40' N.		Lat. 77° 26' N.	
Long. 44° E.		Long. 55° E.		Long. 44° E.	
Depth	° Fahr.	Depth	° Fahr.	Depth	° Fahr.
12 to 114 feet	40·6	6 to 36 feet	36·5	6 to 36 feet	36 to 35·2
		48 „	33·8	45 „	32·5
		60 „	32·0	60 „	32·5
		72 „	30·9	75 „	30·6
		90 „	30·6	90 „	30·4
144 „	36·5	120 „	29·7	120 „	29·1
174 „	35·6	180 „	29·8	180 „	28·8
234 „	34·3				
294 „	32·9	300 „	29·8		
360 „	32·9	.....		360 „	29·1
450 „	32·0				
600 „	31·3				
800 „	29·7				

“The transition of the water from the higher to the lower temperature,” they say “is, near the northern limit, a very rapid one, and nearly everywhere occurs in closest proximity to the ice, so that we were able in the thickest fog to run close up to the barrier under the guidance of the thermometer”*.

16. Thus, then, the additional information obtained from various sources since my last Report has but confirmed the representation therein given (§ 82) of the relation between the Cold and the Warm stratum in the water of the Ocean; and of that relation the doctrine of an upper and an under-flow propounded by Pouillet seems to give the only satisfactory *rationale*.—The existence of such a Vertical Circulation, however, has been called in question by Mr. Croll, on the ground that it is mathematically demonstrable that the force to which I attribute the movement is utterly inadequate to sustain it; and he has even gone so far as to affirm that “it is needless to expect that any further observations in reference to currents in the ocean will in the least degree aid Dr. Carpenter’s theory; for, supposing it were found that the waters of the ocean do circulate in some such manner as he concludes—a *supposition very improbable*—still we should be obliged to refer the motion of the water to some other cause than to that of differences of temperature” (Nature, Jan. 11, 1872). Now as the question is one of great interest to Physical Geographers and Geologists, and as I have very high authority for regarding the whole of Mr. Croll’s reasoning on the subject as fallacious, I shall endeavour to show that the doctrine I advocate involves no inherent improbability, and that the correlation of such a body of observations as it is one of the chief purposes of the Circumnavigation Expedition to collect *may* establish it on a firm basis. At present I claim for it no higher character than that of a “good working hypothesis” to be used as a guide in further inquiry†.

* Geographische Mittheilungen, 1872, p. 70.

† At the Meeting of the Royal Geographical Society, held January 9, 1871, Sir

17. Two separate questions have to be considered, which have not, perhaps, been kept sufficiently distinct either by Mr. Croll or by myself:—*first*, whether there is adequate evidence of the existence of a General vertical Oceanic Circulation; and *second*, whether, supposing its existence to be provisionally admitted, a *vera causa* can be found for it in the difference of Temperature between the Oceanic waters of the Polar and the Equatorial Areas. It is obvious that while the admission of the existence of such a Circulation by no means involves the acceptance of the explanation of it which I have offered, no disproof of the validity of that explanation can neutralize the inferential evidence in its favour which is afforded by the facts of observation. But it is also obvious that if a Force can be shown to be in constant operation, which is adequate to produce the effect I assign to it, the inferences based on the facts of observation are greatly strengthened. And I cannot too strongly protest against the statement that *no body of observations can establish a doctrine*, in opposition to an asserted demonstration of its impossibility, the probative value of which entirely rests upon *a single set of observations*, and upon the *relevancy of those observations* to the question under discussion.

18. I am indebted to the Presidential Address of Mr. Prestwich to the Geological Society in 1871 for the following summary of the older doctrine on this subject, which had been generally lost sight of in this country through the prevalence of the erroneous doctrine of the universality of the temperature of 39° in the Deep Sea, to which I have alluded in former Reports (1868, p. 186, 1869, § 123):—"Humboldt states (Fragmens de Géol. et de Climatol. Asiat., 1831) that he showed in 1812 that the low temperature of the tropical seas at great depths could only be owing to currents from the Poles to the Equator.—D'Aubuisson, in 1819, also attributed the low temperature of the sea at great depths at or near the Equator to the flow of currents from the Poles (Traité de Géognosie, p. 450).—Lenz, in 1831, gave the results of some experiments he had made at great depths in the ocean; and concluded that between the Equator and Lat. 45° the temperature decreases regularly to the depth of 6000 feet, when the decrease becomes insensible. The lowest temperature he recorded was 36° Fahr. (Edinb. Journ. of Science, vol. vi. p. 341).—Pouillet briefly discusses Ocean-temperatures, and concludes that, although all the difficulties of the case are not solved, it seems certain that there is generally an upper current carrying the warm Tropical waters towards the Polar seas, and an under-current carrying the cold waters of the Arctic regions from the Poles towards the Equator (Elém. de Phys. 1847, tom. ii. p. 667)."—The doctrine

Roderick Murchison (speaking through Sir Henry Rawlinson) is reported to have said, with reference to the Paper I read on that occasion:—"From what he had heard of the "Paper on the Law of Oceanic Circulation, it appeared to him that if its conclusions were "borne out by experiment, the announcement would rank, amongst the discoveries in "Physical Geography, on a par with the discovery of the Circulation of the Blood in "Physiology."

was still more explicitly set forth two or three years later by Prof. Buff, in his "Physics of the Earth," as I showed in my First Report (1868, p. 187, *note*); and although his experimental illustration was inappropriate, he very clearly attributed the initiation of the movement to Polar Cold, rather than to Equatorial Heat. It was not to this, as I shall hereafter show (Appendix I., §§ 92, 93), but to the clearly untenable doctrine of Capt. Maury, as to the production of the Gulf-stream and other *sensible currents* by the elevation of level resulting from Equatorial Heat, that Sir John Herschel's trenchant criticism applied; and, as will presently appear, the doctrine advocated in my last Report was explicitly accepted by him shortly before his lamented death (§ 37). So that the general opinion of the most eminent authorities in Physics may be fairly said to have been in favour of the opinion which Mr. Croll dismisses as "a supposition very improbable."

19. The *facts* on which I would lay most stress as justifying the provisional acceptance of this doctrine, may be summarized as follows:—

I. The marked horizontal division of the North Atlantic—the only open Ocean of which the temperature has been yet examined by Serial Soundings—into an *upper* Warm and a *lower* Cold stratum; as shown by the rapid descent of the thermometer in the "stratum of intermixture" between them (§§ 5, 6).

II. The entire absence of any such horizontal stratification in the water of the Mediterranean (§ 7), as also in that of the Red Sea (§ 11) and of the Sulu Sea (§ 12); the temperature of these Inland Basins, beneath the stratum heated by direct insolation, being *uniform* down to their greatest depths.

III. The prevalence of a Temperature averaging 52° at a depth of only 200 fathoms, and of 47° at 400 fathoms, in the Atlantic Ocean between the Tropics (§ 8); where the water, even at these small depths, is *lower* in temperature than at the greatest depths in the Mediterranean.

IV. The prevalence of a Temperature only a few degrees above 32° over the Deep Sea-bed of the North Atlantic generally (Report for 1869, §§ 113–118), as also in the deepest parts of the Indian Ocean, not only to the south (§ 10) but to the north of the Equator (Report for 1869, § 120), and in the China Sea (§ 12); and the deep flow of Polar water, which, as will be shown hereafter (§ 129), underlies the Gulf-stream from the Banks of Newfoundland to the Florida Channel, and there passes beneath the outflowing current *into* the Gulf of Mexico.

V. The prevalence of a Temperature of from 32° to $29\frac{1}{2}^{\circ}$ in the deeper stratum of a portion of the "Lightning Channel" (§ 14); indicating, with the Boreal character of the Fauna of that area, a S.W. underflow of glacial water from the Arctic Sea.

VI. The existence of a Temperature much warmer than the normal of the Latitude, down to a depth of more than 500 fathoms, in another part of the same Channel (§ 13), indicating a N.E. movement of the whole upper stratum in this part of the Atlantic; and the extension of that movement as shown by Thermometric observation, into the Arctic Sea.

20. All these facts (of which Mr. Croll has not even attempted to offer a *rationale*) are brought into harmonious relation by the doctrine of a General *vertical* Oceanic Circulation, from which the Mediterranean and other Inland Seas are excluded (II.) in virtue of the shallowness of their communications with the general Ocean-system. For (I.) the horizontal division of the Atlantic into two strata separated by a marked difference of temperature is thus accounted for, if the upper be conceived as slowly creeping from the Equator towards the Pole, whilst the lower creeps as slowly from the Pole towards the Equator. Next, it fully explains the glacial temperature of the Deep-sea bottom (IV.), which, as the cases of the Mediterranean and the Sulu Sea clearly prove, cannot be attributed to depth *per se*. Again, it gives an adequate reason for the relatively low temperature of the whole mass of Tropical water beneath 200 fathoms depth (III.); this having been drawn into the Tropical area as glacial water, and having risen towards the surface as it received warmth from the crust of the earth on which it rests; the warmer stratum above it being drafted away *towards* the Pole, whilst its place is taken beneath by a fresh arrival of colder water *from* the Pole. Further, it affords an adequate *rationale* for the great body of facts now known (VI.) regarding the abnormally high temperatures met with between Greenland, Iceland, and the coast of Northern Europe; for which the ordinary hypothesis of the extension of the Florida Current or *true* Gulf-stream into that region fails to account, as will be shown in Appendix I. to this Report. The Vertical Circulation is (as it were) epitomized in the "Lightning Channel;" in which there is evidence, from Nautical Observation, of the N.E. movement of the upper warm stratum (VI.); whilst there is inferential evidence of the S.W. movement of the glacial stratum beneath (V.).—Although no experimental evidence has yet been obtained, either of this movement, or of the flow of the deeper stratum of Oceanic water generally from the Polar basins towards the Intertropical zone, indications of such a movement are not wanting. The descent of Icebergs into comparatively low latitudes, in opposition to the current of the Gulf-stream, has been frequently recorded. Two instances of this kind are cited by Dr. Hayes, as having fallen under the notice of Capt. Courtney. On the 27th of April, 1829, he passed an iceberg from 80 to 100 feet high, in N. Lat. $36^{\circ} 10'$ and W. Long. 39° ; and on the 17th of August, 1831, he met with another in N. Lat. $36^{\circ} 20'$ and W. Long. $47^{\circ} 45'$; both having been carried further south than the *southern* edge of the Gulf-stream, which they must thus have crossed.—So, again, according to the statement of Mr. Newall, of Gateshead (kindly communicated to me by Sir Henry Rawlinson), a red-painted buoy, which was attached by a wire rope to the end of the Atlantic Cable cut adrift in 1865, in N. Lat. $51^{\circ} 28'$ and W. Long. $38^{\circ} 42'$, was seen seventy-six days afterwards in Lat. 42° , Long. 40° ; so that it had travelled *nearly due south* about 600 nautical miles, or about eight nautical miles a day. Though it cannot be affirmed with certainty that this change of place was due to the

action of the southerly underflow upon the long rope hanging to the buoy, yet the coincidence of this fact with the preceding, and of both with what the doctrine in question would predicate, may be fairly regarded as evidence of some value in its favour.

21. I now proceed to the second head of the discussion,—viz. the demonstration, which Mr. Croll considers himself to have given, that the difference of Temperature between Polar and Equatorial water cannot possibly produce the effect I attribute to it. He affirms (1) that the utmost difference which can be supposed to exist between the *levels* of the Polar and the Equatorial columns will not serve to produce a movement of the Equatorial surface-water towards the Poles; and (2) that the utmost difference that can be supposed to exist between the *Specific Gravities* of the Equatorial and Polar columns will not serve to produce a flow of bottom-water from the Polar area towards the Equator.—Assuming the temperature of a column of water at the Pole to be 32° from the surface downwards, and the temperature of the Equatorial column to be 80° at the surface, gradually falling to 32° at 10,000 feet, Mr. Croll calculates that the extreme elevation of level of the Equatorial column above the Polar would be 18 feet. “The distance from the Equator to the Poles is about 6200 miles. “The force impelling the water down this slope of 18 feet in 6200 miles “would therefore be equal to about 1-1,820,000th that of gravity. For “example, the force impelling a cubic foot (64lbs.) of water at the surface of “the ocean would scarcely be equal to the weight of one fourth of a grain. “But in reality it would not nearly equal this”*. As evidence of the inadequacy of this force to produce motion in Ocean-water, Mr. Croll relies on the experiments of M. Dubuat; who “found that when the inclination “was 1 in 500,000, the motion of the water was barely perceptible; and “he came to the conclusion that when the inclination is reduced to 1 in “1,000,000, all motion ceases. But the inclination afforded by the difference “of temperature between the sea in Equatorial and Polar regions does not “exceed the half of this; and consequently it can have absolutely no effect “whatever in producing currents.”

22. Now the experiments of M. Dubuat had reference, not to the *slow restoration of level* produced by the motion of water *on itself*, but to the *sensible movement* of water flowing over *solid surfaces* and retarded by its friction against them; and I have the authority of Mr. Hawksley (whose large experience in the construction of Waterworks enables him to speak with high authority on this point) for the statement, that whilst the latter source of retardation is one with which Hydraulic Engineers are well acquainted, the friction with which the former is attended is so slight that it is altogether disregarded in practice. According to Mr. Croll, if a trough 1,820,000 feet long were partly filled with water, and enough water were then poured into it at one end to raise the surface at that end one foot, with a uniform slope to the other end, *that inclination would be permanent*;

* “On Ocean-currents,” in Phil. Mag. Oct. 1870, p. 249.

since "a pressure of one fourth of a grain on the cubic foot of water would "be totally inadequate to overcome the mere molecular resistance of the "water to go into motion." Now not only Mr. Hawksley, but every high Mathematical authority whom I have consulted, has assured me that the "viscosity" of water is so far from having been satisfactorily determined, that the assertion that it would be adequate to prevent water whose level has been disturbed to the extent just mentioned, from ever finding it again, is *totally inadmissible*. The very small degree in which this "viscosity" operates to bring to a stand the *motion of water upon itself*, is shown (as Mr. Hawksley has suggested to me) by the long persistence in the open sea of the "swell" produced by a gale of wind (provided that after the subsidence of the gale there be no counteracting wind), and by the propagation of this "swell" to a great distance*.

23. Now, so far from asserting (as Captain Maury has done) that the trifling difference of level arising from inequality of Temperature is adequate to the production of "ocean-currents," I simply affirm that as fast (or as slowly) as the level is disturbed by change of Temperature, it will be restored by Gravity; and I venture to think that as this is a direct corollary from the fundamental conception of a fluid, the *onus probandi* of the contrary rests on Mr. Croll. When he shall have shown experimentally that water is so viscid a fluid that it does *not* find its own level when time is given to it to do so, he will have obtained a definite foundation for reasoning which is at present simply baseless.

24. But, further, there is an *experimentum crucis* in constant progress, which appears to me completely to disprove Mr. Croll's position. It will not, I presume, be denied by him that the semi-diurnal Tide is produced by the attraction of the Moon, augmented or partly neutralized (as the case may be) by that of the Sun. Now, according to Sir John Herschel†, the Moon's maximum of power to disturb the Earth's waters is only about 1-11,400,000th part of gravity; while that of the Sun does not exceed 1-25,736,400th part of gravity. Yet the Moon's attractive force, even when partly counteracted by that of the Sun (as at neap-tides), suffices to raise and to propagate a vast wave, which, though neither high nor strong in the open Ocean, rises and becomes more rapid where its onward movement is checked, and especially where a large body of water is forced to flow in a narrow channel. Now since the disturbance of Gravity produced by difference of Temperature is many times greater than that produced by the *combined* action of the Sun and Moon, it is for Mr. Croll to show why such a vast force is without effect.

25. Mr. Croll proceeds to say (*loc. cit.* p. 251):—"Suppose that at the "Equator we have to descend 10,000 feet before water equal in density to

* I happen to have myself been subjected for three days continuously, in the middle of the Atlantic, to a heavy swell with a dead calm,—one of the most disagreeable of all nautical experiences.

† 'Outlines of Astronomy,' 3rd Ed., p. 496, note.

“that at the Poles is reached. We have in this case a plane with a slope of “10,000 feet in 6200 miles, forming the upper surface of the water of “maximum density. Now *this slope exercises no influence* in the way of “producing a current, as some seem to suppose; for this is not a case of “disturbed equilibrium, but the reverse. *This slope is the condition of “static equilibrium* when there is a difference between the temperature of “the water at the Equator and the Poles.” Taken by itself, this proposition would seem irreconcilable with the simplest principles of Physics; but I presume that it is to be understood in its connexion with what Mr. Croll seems to regard as a permanent inequality of level between Equatorial and Polar waters. For he goes on to say:—“The only slope that has any “tendency to produce motion of the water is the slope formed by the surface “face of the ocean in the Equatorial regions being higher than the surface “at the Poles; but this is a slope of only 18 feet in 6200 miles.”—Now if, as I maintain, there is *no* such permanent inequality of *level*—any difference produced by inequality of Temperature always tending towards equalization,—the inclined plane of denser because colder water, of which the slope (as admitted by Mr. Croll) must be nearly *two feet per mile*, constitutes a serious disturbance of equilibrium, that must be capable of producing very decided effects.

26. Mr. Croll’s whole manner of treating the subject is so different from that which it appears to me to require, and he has so completely misapprehended my own view of the question, that I feel it requisite to present this in fuller detail, in order that Physicists and Mathematicians, having both sides fully before them, may judge between us: and this must be my apology for dwelling at some length upon considerations so elementary, that I should not otherwise have thought it requisite even to advert to them.—Such, in the first place, is the mode in which Cold applied to the *surface* of an extensive basin of *fresh* water operates in reducing the Temperature of the whole mass. Supposing the cold to be applied to the *entire area* of the basin (as when frost acts on a pond or lake), so that the whole surface-film is chilled at the same time, that film will sink through the sub-jacent water, carrying downwards its reduced temperature—it may be to the bottom of the basin; and a new film from the warmer layer immediately beneath the surface rises into its place. This, being cooled in its turn, sinks until it meets with a layer as cold as itself; its place on the surface being taken by another film from immediately beneath. Of course, these films do not subside without some intermixture and interchange of temperature with the layers through which they successively descend; but they retain enough of their integrity to produce a *downward convection of Cold*, precisely answering to the *upward convection of Heat* which takes place when Heat is applied to the bottom of a vessel of water. This can be readily shown experimentally, by diffusing either colouring-matter, or solid particles of some substance that will remain in suspension when finely divided, through the surface-film. By the successional descent of the surface-

films, and by their successional renewal, the temperature of the whole mass of the water will be progressively reduced, until its density reaches its maximum at $39^{\circ}2$; after which the further application of cold no longer causes the descent of the surface-film. And thus it comes to pass that the temperature of all the water beneath that superficial stratum which undergoes further reduction of Temperature with increase of Specific Gravity until it freezes, is uniform throughout, down even to the very bottom of such deep basins as some of the Italian and Swiss lakes; and that, as there is no downward convection of Heat when the summer sun acts on their surface, and the only warming influence will be that of the crust of the Earth beneath, the temperature of $39^{\circ}2$ is found to prevail throughout the year from a small distance beneath the surface of the deeper lakes down to their very bottom.

27. But the case is very different with *Sea-water*, which does not attain its maximum of density until it freezes (at or below 27°); for the downward convection of Cold will continue until any further reduction of temperature produces the formation of ice; and thus we should expect to find the *deepest* stratum of *Sea-water* that has been acted on by surface-cold showing the *lowest* temperature, which is precisely what we have ourselves met with in the "Lightning Channel" (§ 14), where we found $29^{\circ}6$ at 640 fathoms, and what Messrs. Payer and Weyprecht met with in Lat. 78° very near the surface (§ 15)*.

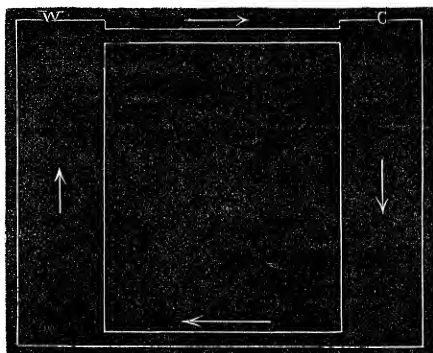
28. Let us next suppose that only *a portion of the area* of the basin is exposed to the action of surface-cold; the movement of the liquid takes place somewhat differently. For the surface-film which descends is then replaced, not from beneath, but by an inflow from the neighbouring area, as may be proved experimentally by the means already indicated†: and

* Mr. Croll (Phil. Mag., Oct. 1871, p. 248, note) speaks of it as "a well-established fact that in Polar regions the temperature of the sea decreases from the surface downwards; and the German Polar Expedition found that the water in very high latitudes "is actually less dense at the surface than at considerable depths, thus proving that the "surface-water could not sink in consequence of its greater density."—Now if, as all recent observations concur to prove (§ 15), the temperature of Polar water shows a progressive reduction, with increase of density, from the surface downwards,—save where the melting of ice has reduced the salinity as well as the temperature of surface-water, thus making it lighter as well as colder,—surely the decrease of temperature indicates that as fast as the surface-water is chilled by the colder air above, it sinks and carries its cold downwards. In what other way the *deepest* water can come to be the *coldest*, I am at a loss to comprehend.

† Mr. Croll objects (*loc. cit.* p. 244) to the Experiment which I described in my last Report (§ 129), on the ground that the mode in which the heat was applied at the opposite end of the trough would establish a circulation by "a horizontal propulsion of "water caused by the expansive force of vapour, and that the movement was not in any "way due to difference of specific gravity."—Now if Mr. Croll will try this experiment for himself, he will find that the circulation is clearly *initiated* at the *cold* end of the trough; the coloured water, as it comes in contact with the ice, *tumbling down* (as it were) to the bottom of it, and then flowing horizontally without any application of heat to the other end of the trough. And this movement goes on, though at a progressively

when this chilled surface-film has reached the bottom, instead of limiting itself to the area of superficial exposure to cold, it flows off laterally in every direction; and this lateral outflow will go on so long as the disturbance of equilibrium is maintained by the cooling of the surface-films which are successively drawn into the area.

29. That such *must* be the case, appears to me so self-evident that I am surprised that any person conversant with the principles of Physical Science should hesitate in admitting it, still more that he should explicitly deny it. But since others may feel the same difficulty as Mr. Croll, it may be worth while for me to present the case in a form of yet more elementary simplicity.—Let us suppose two cylindrical vessels of equal size to be filled with Sea-water to the same level, but the temperature of the water in one of them (W) to be 60° , while that of the other (C) is 30° ; it is obvious that the pressure exerted by the latter column upon the bottom and sides of the cylinder it occupies must be greater than that exerted by the former, in proportion to its excess of Specific Gravity. If, now, communications be opened between the two by transverse pipes at the top and bottom of each cylinder, an outflow of cold water will take place by the lower pipe from C to W, and an inflow of warm water by the upper pipe from W to C, until



equilibrium is restored; which it will be by the transfer of the *lower half* of the *cold* column from C to W, and of the *upper half* of the *warm* column from W to C. But if the water which flows through the upper pipe from W to C be subjected, on entering the top of C, to a surface-cold which

diminishing rate, provided the action of Cold is continuously maintained; and would thus continue until the whole of the water is reduced to the temperature of its greatest density, when it would come to an end by the equalization of specific gravity throughout. The application of Heat at the other end of the trough only serves to *maintain* the circulation, by keeping up the *difference* of temperature which is necessary for the continued disturbance of the equilibrium which the circulation is always tending to restore. The *horizontal* flow of the chilled water along the *bottom* of the trough is clearly due to the greater *downward* and therefore *lateral* pressure of the column at the cold end, resulting from its constantly renewed excess of density.

reduces its Temperature to 30° , and proportionally augments its Specific Gravity, then (the levels of the two columns being equalized by such inflow) the excess of weight in column C will be maintained, until, by the continued outflow through the bottom pipe, the whole of the warm water in column W has been transferred to C; for this outflow lowers the level in C, and at the same time tends to lift up the superincumbent warm water in W, which will consequently flow back through the upper pipe into C, so as to restore the equality of the levels of the two columns. And if *all* the water which passes from W to C is cooled down on entering C, this circulation must continue, though at a gradually diminishing rate, until equilibrium is restored by the depression of the temperature of the entire water of *both* columns to 30° .—But let us suppose, further, that the cold water, as it enters the bottom of W by the lower pipe, has its temperature *raised* again by warmth applied beneath; and that this elevation is further increased by surface-heat as the water rises to the top of the column; the result will be that, as the temperature of the water in column W, except of that lowest stratum which has last arrived from C, will be kept constantly above that of column C, whilst there will be a constant tendency to the equalization of the levels of the two columns, there will be a continually renewed difference between their Specific Gravities and consequently between their absolute weights. This will produce a continual transference of water from the *bottom* of C to the bottom of W, and from the *top* of W to the top of C, with a constant *descending* movement in C and a constant *ascending* movement in W. The descending movement in column C will not consist in a successional descent of surface-films from above downwards, unless it should happen that the surface-cold is intense enough to reduce their temperature below that of the subjacent water; but it will be a *downward movement of the entire mass*, as if water in a tall jar were being drawn off through an orifice at the bottom. And in like manner the upward movement in column W will not so much consist in a successional ascent of bottom-films, as in an *upward movement of the entire mass*; since the films warmed at the bottom will only ascend until they meet with water of which the temperature is as high as their own; and this will be the case so soon as they have passed through the cold stratum which has last flowed in from C. The force which will thus lift up the entire column of water in W, is that which causes the descent of the entire column in C, namely, the excess of Gravity constantly acting in C; the levels of the two columns, and consequently their heights, being maintained at a constant equality by the free passage of surface-water from W to C.

30. The whole of Mr. Croll's discussion of this question, however, proceeds upon the assumption that the levels of the Polar and Equatorial columns are *not* kept at an equality, in consequence of the inadequacy of the excess of level in the Equatorial column to put in motion the intervening water; and that instead of there being an *excess of weight* in the Polar column, there is a condition of *static equilibrium* between the two.—

Having shown the untenableness of this assumption (§ 22), I might dismiss his arguments without further notice, were it not that I should leave it in his power to reply that, granting *my* view of the case to be the correct one, the force of Gravity which I regard as the *primum mobile* of the Circulation cannot be greater than it is on *his*.

31. In order to show how a disturbance of Static Equilibrium produced by difference of Temperature would operate through a vast extent of Ocean, I shall suppose an elongated Inland Sea like the Mediterranean, with a uniform temperature of 54° throughout, to have one-tenth of its length cut off from the rest by a septum, and the whole surface of this portion to be acted on by Polar Cold, until the temperature of the entire body of water it contains should be reduced to 27° ; its level being thus lowered, and its Specific Gravity augmented, without any increase in its absolute weight. If, now, we suppose the septum to be removed, it is evident that not only will the depression of level produce a surface-inflow into the Cold area, from the portion of the basin next adjacent to it, but that the compensatory movement *must* extend, though in a gradually diminishing ratio, to the opposite extremity of the basin: for, if it do not, either water is *not* a liquid, or liquids do *not* find their own level. The water of the Cold area, having its surface now raised to the general level of the basin, will have its absolute weight augmented in proportion to its increase in density; and both its downward and its lateral pressure will therefore be in excess of that of every other column of equal height and base in the entire basin. Now Mr. Croll's position is, that the difference in Gravity between the two columns A and Z at the opposite ends of the basin is a force too small to give motion to the whole intermediate series of columns (B to Y); which is equivalent to saying that the heavier water in column A will be *permanently banked up* by the resistance of columns B to Z; so that the state of disturbed Equilibrium produced by the original reduction of Temperature will last so long as that reduction is maintained.

32. Now as such a position is inconsistent, not merely with the *theoretical* conception of a liquid, but with *facts* capable of being verified by daily observation, there must obviously be a fallacy somewhere: and this fallacy seems to me to lie in Mr. Croll's treatment of the whole mass of water *en bloc*, as if it were a solid body; instead of regarding it as a liquid, of which each component part, being free to move upon every other (*retarded* only by its "viscosity"), carries from point to point along the whole length of the basin the action of the force *initiated* at the cold end. In order to determine how this force will operate, we must begin by considering what change will occur between the water of the cold and heavy column (A), and that of the warmer and lighter column (B) next adjacent to it, when free communication has been opened between them. The difference in the weight of the two columns involves an excess of lateral pressure in column A, increasing from above downwards; and this will cause a *bottom outflow* of the heavier stratum from A to B, which, by lowering the level

of A and raising that of B, will produce a further *surface-indraught* from B into A. Supposing B to be cut off by a septum from the rest of the basin, as A was in the first instance, this interchange would proceed until half of the heavier water of column A has flowed into the lower part of column B, and half of the lighter water of column B has flowed into the upper part of column A, so as to equalize the pressure and the level in the two. If now the septum be removed between columns B and C, the excess of pressure which B shares with A will operate in like manner (though in a diminished measure) against C; and the same interchange will take place until the equilibrium is restored. And thus by a propagation of the like interchange through the whole succession of columns in a progressively diminishing ratio, the stratum of colder and heavier water (supposing its temperature not to be altered by conduction from below or from above) would ultimately spread itself at a uniform level over the entire floor of the basin. This extension, in fact, would be simply a question of *time*, like the equalization in the level of its surface; the rate of the movement being determined by the "viscosity" of the water.

33. But we have now to trace out the result of the *continued* action of severe Cold on the surface of the limited area at one extremity of the basin. As fast as the *bottom-outflow* tends to restore the equilibrium between the Polar column and the rest of the basin, a new disturbance will take place by the cooling of the water brought in by the *surface-inflow*; and this disturbance will be propagated onwards from column to column, along the whole length of the basin, in the manner just indicated. If the glacial stratum were not to acquire any heat in its diffusion over the floor of the basin, its thickness would be continually augmented by fresh exchanges between column and column,—the warmer *surface-water* flowing *towards* the cold extremity of the basin, as fast as cold *bottom-water* flows from it; until at last the *entire mass* of the water in the basin (supposing its surface-temperature not to be kept up by insolation) would have its temperature progressively reduced by *downward* convection in the area over which the cold directly acts, and thence by *lateral* convection, until the whole would be brought down to 27°, when no further movement would take place.

34. But since the Glacial stratum, as it creeps along the sea-bed, is continually receiving heat from the crust of the earth beneath and from the warmer layer of water above, its thickness would diminish with the increase of distance from the Polar area; or, in other words, its surface would form an inclined plane, lying at a greater and yet greater depth, the further it has flowed from its source,—which is just what, so far as our present knowledge extends, proves to be the case. And further, as the upper stratum is being continually draughted off in the opposite direction, the portion of the glacial stratum which has had its temperature raised by the agencies just noted, and which overlies the rest, will be lifted into its place by the intrusion of a fresh arrival of colder water beneath, so as to

come under the direct influence of insolation ; whereby its temperature will be greatly augmented, and its level raised, so as to promote the return-flow. Thus at the two extremities of the basin there will be two forces in constant renewal, the opposing actions of which will as constantly tend to a *disturbance* of equilibrium ; and to deny that a movement will thus be produced and sustained, tending to the *restoration* of equilibrium through the entire basin, is simply to assert that a constant force acting on particles that are free to move does not move them.

35. It is to be remembered that, however small the original amount of movement may be, a *momentum* tending to its continuance *must* be generated from the instant of its commencement ; so that if the initiating force be in constant action, there will be a *progressive acceleration* of its rate, until the increase of resistance equalizes the tendency to further acceleration. Now if it be admitted that the propagation of the disturbance of equilibrium from one column to another is simply *retarded*, not prevented, by the “viscosity” of the liquid, I cannot see how the conclusion can be resisted, that the constantly maintained difference of Gravity between the Polar and Equatorial columns really acts as a *vis viva* in maintaining a Circulation between them. A remarkable confirmation of my argument as to the sufficiency of difference in Specific Gravity to keep up a Vertical Circulation, is afforded by recent researches on the Dardanelles Undercurrent. (See § 173.)

36. Those who are accustomed to look only at the movements of *great volumes* of fluid, and to discuss them *en masse*, are apt to ignore facts perfectly well known to such as have had occasion to observe those minuter changes which are constantly taking place within any collection of liquid under the influence of slight alterations of Temperature.—The following is a remarkable example of this kind, which fell within my own knowledge many years ago, and made a strong impression upon me. Mr. West, a very ingenious mechanician at Bristol, having heard of the success of Mr. Peter Barlow’s plan of constructing object-glasses for Telescopes of moderate aperture, in which the double concave of flint-glass was replaced by a highly refracting fluid (such as sulphuret of carbon, or oil of cassia), carried out this plan on a large scale in the construction of an object-glass of eighteen inches in diameter. By the mathematical aid of Mr. Barlow, and his own great mechanical ability, this object-glass (exceeding in diameter that of any refracting telescope which had been at that time constructed) was completed with theoretical correctness ; but when it was brought into use, its performance was found to be so seriously impaired by movements produced in the fluid by the very slight disturbances in the equality of the Temperature of its different parts, occasioned by atmospheric currents, that in spite of every precaution which could be taken for its protection, it was found to be valueless for the purpose of Astronomical research.—Those, again, who have been accustomed to the minute observation of *Aquaria*, have frequently noticed currents, marked by the movement of minute suspended particles,

that could only be attributed to slight differences of Temperature ; and Dr. Möbius*, who has given much attention to this inquiry, has ascertained that a difference of *half a degree* of Reaumur is quite sufficient to produce *sensible movement*.—Further, Mr. Rainey, who has paid great attention to the internal motions of small collections of liquid entirely enclosed within glass and placed under the Microscope, has recently published a series of observations, which show that definite currents, made obvious by the translation of suspended particles, take place in liquids thus enclosed, under conditions that seem to exclude any other agencies than inappreciable differences of Temperature. (St. Thomas's Hospital Reports, New Series, vols. i. & ii.)

37. I have not, indeed, learned that any eminent Physicist endorses Mr. Croll's objections to the doctrine I advocate ; whilst I have, on the other hand, had the satisfaction of receiving from both Sir John Herschel and Sir William Thomson an explicit acceptance of it. The former was kind enough to write to me, only a short time before his last illness, as follows :—"Assuredly, after well considering all you say, as well as the common sense of the matter, and the experience of our hot water circulation-pipes in our greenhouses, &c., there is no refusing to admit that an Oceanic circulation of some sort must arise from mere Heat, Cold, and Evaporation, as *veræ causæ* ; and you have brought forward with singular emphasis the more powerful action of Polar Cold,—or rather, the more *intense* action, as its maximum effect is limited to a much smaller area than that of the maximum of Equatorial Heat. The action of the Trade and Counter-trade Winds in like manner cannot be ignored ; and henceforward the question of Ocean-currents will have to be considered under a twofold point of view. The Wind-currents, however, are of easier investigation. All the causes lie on the surface : none of the agencies escape our notice ; the configuration of coasts, which mainly determines their direction, is patent to sight. It is otherwise with the other class of movements : they take place in the depths of the Ocean ; and their movements, and directions, and channels of concentration, are limited by the configuration of the sea-bottom, which has to be studied over its whole extent by the very imperfect method of Sounding."

38. Imperfect as that method is, however, I cannot but believe that a sufficient number of *Serial* Temperature-soundings, taken in different parts of the Oceanic area, especially in the Southern Hemisphere, will afford adequate data for the settlement of the question whether such a Circulation actually exists ; and also that means may be found for determining its rate by observation and experiment. If such determinations can be made, I am assured by Mathematicians that they will afford valuable data for the accurate determination of the "viscosity" of water, which is at present by no means the *known* quantity assumed by Mr. Croll. It is consequently with great satisfaction that I look forward to the results of the inquiries to be prosecuted in this direction by the Circumnavigation Expedition now being fitted out by Her Majesty's Government.

* See 'Annals of Natural History,' Ser. 4, vol. viii. p. 201.

39. If the views I have propounded be correct, it may be expected that near the border of the great Antarctic Ice-barrier, a Temperature below 30° will be met with (as it has been by Parry, Martins, and Weyprecht near Spitzbergen, § 15) at no great depth beneath the surface; and that instead of *rising* at still greater depths, the thermometer will *fall* to nearly the freezing-point of salt water. The greater the distance from the ice-barrier, the greater would be the depth at which the surface of the Glacial stratum would be met with; but in consequence of the free communication between the Antarctic area and the great Southern Oceans, it may be expected that the deepest parts of these will be found to show a temperature as low as 32° , or perhaps lower, even near the Equator.—The bottom-temperature of the North Pacific will afford a crucial test of the truth of the doctrine. For since the sole communication of this vast Oceanic area with the Arctic basin is a Strait so shallow as only to permit an inflow of *warm* surface-water, its deep cold stratum must be entirely derived from the *Antarctic* area; and if its bottom-temperature is not actually higher than that of the South Pacific, the glacial stratum ought to be found at a greater depth *north* of the Equator than *south* of it. In the North Atlantic, again, the comparative limitation of communication with the Arctic area may be expected to prevent its bottom-temperature from being reduced as low as that of the Southern Atlantic. But it will be a matter of peculiar interest to determine the bottom-temperature of the deep channel that separates Greenland and Iceland, to ascertain the thickness of the Glacial stratum which (I venture to predict) will be found to occupy a large proportion of its entire depth, and to trace the gradual thinning-out of this, as it diffuses itself over the vast area of which the bottom-temperature is reduced by it.

40. It will further be extremely important to ascertain by Mechanical means, if possible, whether this Glacial flow has a movement of which the direction and rate are determinable. And I would especially point out that the “Lightning Channel” (§ 14) affords a peculiarly favourable opportunity for such investigation, in consequence of the well-marked distinctness of its two strata. If my view be correct, a “current-drag” suspended in the *upper* stratum ought to have a perceptible movement in the N.E. direction; whilst another, suspended in the *lower* stratum, should move S.W. And though the *rate* of movement in each may be very slow, yet the opposition of their *directions* may be expected soon to make itself apparent, in the separation of the surface-buoys from which the drags are suspended.—Should the examination of this Northern portion of the Oceanic area be beyond the scope of the Circumnavigation Expedition, I would urge that it should be undertaken by any Polar Expedition which the British Government may fit out. For the difference in the Thermal conditions of the Northern and Southern Oceans, consequent upon the difference in their respective relations to the Arctic and Antarctic basins, is a question of peculiar interest in a Geological point of view.

41. If, again, as may be anticipated, it should prove that a considerable

difference exists between the bottom-temperature of the North Pacific and that of the North Atlantic, it is evident that if there ever was a time at which a continuous Continent extended from Greenland to Scandinavia, the North Atlantic would then have been cut off from the Polar basin almost as completely as the North Pacific is now, and its bottom-temperature would be higher than we now find it. If, on the other hand, there should ever be such a subsidence of the Peninsulas of Alaska and Eastern Siberia, as would open a free communication between the Arctic basin and the North Pacific, the temperature of the lower stratum of the latter would probably be greatly reduced.

42. How important would be the Geological and Biological effect of such changes, and how great a light may be thrown on Palæontology by such inquiries as I have indicated, was admirably shown by Mr. Prestwich in the Presidential Address which he last year (1871) delivered to the Geological Society. After pointing out how entirely the Thermal condition of the Mediterranean differs from that of the Atlantic, in consequence of its exclusion from the general Oceanic circulation, he suggests whether the deep Sea in which the Chalk of Europe, with its more Tropical genera, was deposited may not also have been a sea shut out from direct communication with Arctic seas. As the Cretaceous Ocean formed an east and west belt across the present Continents of Europe and Asia, we must look for "dry land on the confines of that ocean; and it is probable that the latter may have been, to the north, in the direction between Greenland and Scotland and Scandinavia, where the present ocean is some hundreds of fathoms shallower than further south. We know that towards the end of the Cretaceous period a change took place in the Fauna, arising apparently from the shallowing of the sea that preceded the deposition of the Maestricht beds. Many of the great Cephalopods disappeared, and Reptiles increased in numbers; at the same time the Lamellibranchiate Mollusca became more predominant." . . . "If such a northern land barrier as that which I have alluded to existed at the period of the Chalk, and that barrier was submerged during the early part of the Tertiary period, it would (taken in connexion with the very different conditions of depth under which the Chalk and Lower Tertiaries were formed) go far to account for the great break in the Fauna of the two periods. Some years since I had occasion to show on other grounds that the Thanet Sands, which repose on the Chalk in the South-east of England, exhibited a Fauna essentially of temperate or cold latitudes; and I inferred the inset of currents from the north."

43. It is regarded by Mr. Prestwich as highly probable that the old Cretaceous ocean was prolonged into the American Cretaceous area, across the present Atlantic; and he thinks "that the hypothesis with regard to the continuity of that sea-bed from the period of the Chalk to the present period is one of high probability." Now this *continuity* is all that it was intended by Prof. Wyville Thomson and myself to express by the phrase

used in my First Report (1868, p. 193), that "we may be said to be still living in the Cretaceous epoch." We then anticipated—what our own subsequent inquiries and those of our friends of the United States Coast Survey have abundantly confirmed—that with the persistence of the Globigerine life which *forms* the Cretaceous deposit, there would prove to be a like persistence of numerous types characteristic of the old Cretaceous Fauna; so that the *Globigerina*-mud now in process of increase on the sea-bed of the Atlantic may be regarded "not merely as a Chalk-formation, but as a continuation of the Chalk-formation." Now we have been told on high authority that Geological epochs are essentially marked out by great changes in the Fauna,—whole series of Animal forms disappearing, and their places being taken by others which then first make their appearance; and further, that the termination of the Cretaceous Epoch must be considered, in this sense, as coinciding with the disappearance of those numerous types of chambered Cephalopods which were so eminently characteristic of the Old Chalk, and of which very few appear to have survived the changes that inaugurated the Tertiary epoch*.

44. There is nothing really inconsistent, however, between Sir Charles Lyell's view of the case and our own. If his definition of a Geological Epoch be accepted, then our doctrine that "we may be said to be still living in the Cretaceous epoch" requires to be expressed in somewhat different language. But if that which we meant to be understood by it, and which has been admitted as probable by so eminent an authority in Geology as Mr. Prestwich, should be really the case, then, I submit, some new term must be invented to designate that state of things which will present itself to the "Geologist of the future," whenever the present bed of the Atlantic shall be raised into dry land. For there will then be found superimposed upon the newest beds of what is now known as the "Cretaceous Formation," not a series of deposits resembling the Tertiaries of Europe and America, but an unbroken succession of layers of a substance resembling the Old Chalk in all essential particulars†, and containing numerous Animal types which do not differ more from those of its uppermost beds than these do from the types found in the earlier members of the Formation. Doubtless there will be a great and perhaps a sudden change in certain portions of the Fauna; but whilst the material of the deposit continues unchanged, whilst its Stratification remains conformable, and a large number of Generic types can be traced continuously throughout, I venture to think that the

* Sir Charles Lyell's 'Student's Elements of Geology,' p. 263.

† Much stress has been laid on the fact that the specimens of the Atlantic mud brought up by our dredge proved on analysis to contain a considerable admixture of Sand, and could not be said to be true Chalk. But this admixture may very probably have been purely *local*, resulting from the drift of the Northern *detritus* along a line of specially rapid underflow. According to Dr. Bailey and Prof. Huxley, the Atlantic mud brought up by the Sounding-apparatus from the Mid-ocean scarcely contained a trace of sand; and the non-communication of the Cretaceous Sea with the Polar area may not improbably be the explanation of the purity of the Old Chalk.

"Geologist of the future" would scarcely think himself justified in limiting the "Cretaceous Formation" to beds distinguished only by the presence of a certain set of Animal forms not to be found in those above them. If, however, he should think proper so to limit that term, he would have to invent a new one for the later beds deposited in absolute continuity with it, and perhaps in all but one particular under the same conditions. That particular, if Mr. Prestwich's very ingenious speculation be accepted as provisionally true, was Temperature; a reduction in that of the Cretaceous Sea, consequent upon the opening of a communication with the Arctic basin (by changes in level perhaps thousands of miles off), being an adequate *vera causa* for the disappearance of all those animals which are dependent on a warmth approaching the Tropical; whilst those which could adapt themselves to the change (perhaps with some modification of structure) would maintain their ground, and would in their turn leave their remains to be entombed in the mass of *Globigerina*-mud, the production of which on the Atlantic sea-bed seems to have gone on uninterruptedly through the whole of the Tertiary Period to the present time.

45. I have thought it not inappropriate to conclude this portion of my present Report with a recurrence to a subject brought into prominence by Prof. Wyville Thomson and myself three years ago; partly because I thus obtain an opportunity of explaining what was really meant by a somewhat incautious expression, and partly because a new value is given to the doctrine which that expression was intended to convey by Mr. Prestwich's explicit acceptance of it, coupled with his ingenious application of the doctrine of a General Oceanic Circulation to account for the disappearance of the more Tropical portion of the Cretaceous Fauna, without change in any other condition than Sea Temperature.—This, as it appears to me, is a singularly felicitous example of the valuable results which may be expected from the wider extension and more systematic prosecution of the inquiries in which it has been my privilege to take part, and which I now leave in the hands of the valued Colleague by whom they were originally suggested; entertaining the fullest confidence that they will be carried on with zeal and ability, and a sanguine hope of their distinguished success.

PART II.

FURTHER INVESTIGATION OF THE GIBRALTAR CURRENTS.

46. The inquiries made in the 'Porcupine' Expedition of 1870 having shown that the information obtainable by the Hydrometer respecting the *stratification* of Atlantic and Mediterranean water in the Strait of Gibraltar might afford valuable evidence in regard to their movement, I made the determination of Specific Gravities my own special charge, whilst Capt. Nares, in consultation with me, carried out the Mechanical portion of the investigation. As his separate Report of the inquiries he conducted, and of the deductions he drew from them, has been already communicated to

the Royal Society by the Hydrographer to the Admiralty, and has been published in its 'Proceedings' (Jan. 18, 1872), there will be no occasion for me to do more than state the results of my own Sp. Gr. determinations, and compare these with the results obtained by the use of the "current-drag," in such a manner as to enable every reader to judge for himself whether my own conclusions are or are not justified by the facts now adduced. —That the *complete* elucidation of the question requires a much more prolonged and systematic study than it was in our power to make on this occasion, is the opinion at which we have both arrived; and since the knowledge to be gained by such an investigation would be highly serviceable to the Navigator, whilst affording most valuable data for the Scientific study of Tidal and Current movements generally, I shall include in this Section of my Report some suggestions for its further prosecution.

47. It will be remembered that between Capes Trafalgar and Spartel, at the western or Atlantic entrance of the Strait, is a "ridge" which constitutes a kind of marine "watershed," looking on one side towards the Atlantic, and on the other towards the Mediterranean. The depth of the northern half of the channel across this section scarcely anywhere exceeds 50 fathoms; whilst in its southern half the depth does not seem anywhere to reach 200, and may be considered to average 150 fathoms. From this "ridge" the Atlantic slope deepens gradually westwards, until, at a distance of about 45 miles, a depth of from 500 to 600 fathoms is reached. On the other hand, the Mediterranean slope deepens gradually eastwards along the whole length of the Strait (about 35 miles), as far as its *embouchure* in the Mediterranean between Gibraltar and Ceuta, where the depth of the deepest part of the channel exceeds 500 fathoms. Thus it appears that the Strait is to be considered as a prolongation of the Mediterranean basin, not of that of the Atlantic. If its bottom were to be elevated 200 fathoms, the "ridge" would become dry land, entirely cutting off the Mediterranean from the Atlantic; but though the channel between the European and the African shores would be considerably narrowed, it would still extend further west than Tangier. If thus completely cut off from the Atlantic, the Strait would be in every sense a part of the Mediterranean, and would be entirely filled with the denser water of that great Inland Sea. But in virtue of its communication with the Ocean outside, and of the continual inflow (modified by tidal changes) of a surface-current from the Atlantic, the whole *upper* stratum of the water of the Strait has a purely Atlantic character, which is as distinctly recognizable by the Specific-Gravity test at the Mediterranean as at the Atlantic end of the channel. On the other hand, the *lower* stratum was last year found no less distinctly to correspond in Specific Gravity with the denser water of the Mediterranean; so that its presence could be recognized by this character no less certainly on the summit of the "ridge" than in the deepest portion of the Mediterranean embouchure. (See Report for 1870, §§ 61–69.)

48. I made it, therefore, my first object to ascertain whether the pre-

sence of Mediterranean water could be detected by an excess in the Specific Gravity of the bottom-water, on the *Atlantic* side of the slope; our previous inquiries having shown that no such excess is to be found in the ordinary water of the Atlantic, which appears to be even a little *more* saline at the surface than below it,—the effect of this excess on Specific Gravity being neutralized by the expansion produced by the more elevated Temperature (Report for 1870, § 84). The average of our determinations of the Sp. Gr. of Atlantic water had been 1·0265, the *minimum* (bottom) being 1·0261, and the *maximum* (surface) 1·0269; and this agrees very well with the results obtained by Forchhammer,—who, moreover, explicitly states that while the water taken between Lat. 20° and 30° off the western coast of Africa has a Salinity approaching that of Mediterranean water (which he attributes to the great evaporation, and to the absence of river-return of fresh water), the surface-water of the Atlantic embouchure of the Straits, for some distance westward, has the average density of Atlantic water*.

49. The first sample we obtained of bottom Atlantic water within the influence of the Mediterranean outflow, was by the deep Sounding already mentioned (§ 3) as having been taken on the 19th of August, in Lat. 36° 47' N., and Long. 9° 39' W., about 45 miles W.S.W. of Cape St. Vincent. The Sp. Gr. of the *surface*-water being here 1·0268, that of the *bottom*-water was 1·0281.—Our next sample was obtained on the 20th of August from a depth of 665 fathoms in Lat. 36° 2' N. and Long. 7° 43' W., in the direct line of the axis of the Strait, and about 90 miles to the west of the "ridge." The Sp. Gr. of the *surface*-water was here 1·0269, and that of the *bottom*-water 1·0280. Proceeding eastwards in the direction of Cape Spartel, we took on the following day a succession of samples from the gradually shallowing bottom of the Atlantic slope; and the Specific Gravities of these, as compared with those of the surface-water at the same points, are given (with the preceding) in the following Table:—

Station.	North Latitude.	West Longitude.	Depth in Fathoms.	Sp. Gr. at Surface.	Sp. Gr. at Bottom.
1.	36° 47'	9° 39'	1560	1·0268	1·0281
2.	36° 2'	7° 43'	665	1·0269	1·0280
3.	35° 47½'	6° 41'	355	1·0269	1·0282
4.	35° 43'	6° 34'	290	1·0270	1·0281
5.	35° 40'	6° 28'	225	1·0270	1·0282
6.	35° 38'	6° 25'	115	1·0270	1·0278
7.	35° 47'	6° 24'	325	1·0270	1·0285

Thus it appears that along the whole of this line of Soundings there is a most decided excess in the Specific Gravity of the *bottom*-water over that of the *surface*-water, and that this excess increases as the "ridge" is approached,—the exception shown at Station 6 being really a proof of the rule; for at that Station there was obviously a rise of the bottom from a

* Phil. Trans., 1865, pp. 220, 223.

deep valley, since we passed from 115 to 325 fathoms by merely shifting our position about 7 miles to the northward; and the heavier water would of course gravitate towards the greater depth, where (Station 7) we found the *maximum* of density anywhere met with on the *Atlantic* slope of the "ridge."

50. Taking these facts in connexion with those to be next stated in regard to the Specific Gravity of the water at different depths within the Strait (*i. e.* on the Mediterranean slope of the "ridge") and on the "ridge" itself, I cannot but regard it as a fair conclusion that this excess is due to the *deep outflow of Mediterranean water* over that ridge. It is not a little significant that the effect of this outflow should be so distinctly traceable as far as Station 1,—a fact which seems to me to negative the hypothesis of Captain Spratt, that this dense bottom-water is derived from the remote region of the Atlantic to the south of 30° Lat.: for (1) the excess of evaporation in that area must be effectually neutralized, in the area between Cape St. Vincent and Mogador, by the vast quantity of fresh water brought down by the Guadiana, the Guadalquivir, and the rivers of Morocco; whilst (2) all our knowledge of the movement of Oceanic water along the N.W. coast of Africa (§ 63) indicates that it has a *southward* rather than a northward direction. Further, the Temperature observations made both last year (Report, §§ 75, 76) and this year (§ 62), indicate that any *surface-outflow* of Mediterranean water is more likely to take place along the European than along the African side.

51. Proceeding within the Strait, we took up on August 21st our first position off Tarifa, where a sample of water taken from the *bottom* at 330 fathoms gave the high Specific Gravity of 1·0293; clearly showing its Mediterranean character. Samples taken at depths of 200 and 150 fathoms gave almost exactly the same Sp. Gr., as did also a second pair of samples taken in nearly the same part of the Strait at 150 fathoms and 125 fathoms; from a comparison of which observations with those taken between Gibraltar and Ceuta (§ 54), it appears that the dense Mediterranean water lies about 100 fathoms nearer the surface over a 300 fathoms bottom, than it does where the bottom sinks to more than 500 fathoms.—It was not a little unexpected to find a marked excess in the density of the *surface-water* in the first set of observations, its Sp. Gr. being as high as 1·0275. This seemed attributable to the prevalence of a fresh Easterly wind, producing a westward drift of Mediterranean water that mingled with the surface inflow from the Atlantic; it must, however, have been local and transient, since at a later part of the day, in nearly the same spot, the Sp. Gr. of the surface-water was found to have returned to its ordinary standard (within the Strait) of 1·0271.—The observations made this day with the Current-drag, although not so continuous or complete as those taken subsequently, made it clear that both the upper and the under-current are not only greatly influenced in *rate*, but may be completely reversed in *direction*, by Tidal agency. One hour after High water, the

surface-stratum was found to be moving *eastwards* at the rate of 1·7 mile an hour; $3\frac{1}{2}$ hours later, the direction was still the same, but the rate had diminished to 1·5 mile an hour; 2 hours after Low water, when the tide was rising, the *surface*-current was moving to the *westward* at the rate of 1 mile per hour; and at 4–5 hours after Low water, its direction being still the same, its rate of movement had fallen to 0·4 mile per hour. In the earlier part of the day, the *under*-current at 150 fathoms was found to be moving to the *eastward*, but an accident prevented the determination of its rate. In the afternoon, however, 2 hours after Low water, a current-drag suspended at a depth of 125 fathoms moved *westward* at a rate of 1·35 mile an hour; which, allowance being made for the resistance to the motion of the *surface*-buoy, was considered by Capt. Nares to indicate that the rate of westward flow of the *under*-current was really 1·5 mile per hour, exceeding that of the *surface*-movement in the same direction by 0·5 mile.

52. On the following day we took up our position on the north part of the "ridge" between Capes Spartel and Trafalgar, over a bottom of 125 fathoms depth. The weather being very calm, and the water smooth, every thing was favourable to the prosecution of our inquiries. The Specific Gravity of the *surface*-water being 1·0271, and that of the *bottom*-water 1029·2, the presumption was very strong that, while the *upper* stratum consisted of Atlantic water, the *lower* stratum consisted of Mediterranean water; and the first question to be determined was the depth of each. We found that at 50 fathoms the Sp. Gr. had increased to 1·0273, and that at 100 fathoms the Sp. Gr. showed a further increase to 1·0276; but that a marked increase from this to 1·0290 showed itself before the depth of 110 fathoms was reached; so that while the lower part of the Atlantic stratum showed a sufficient admixture of Mediterranean water to affect very sensibly its Specific Gravity, the stratum below 110 fathoms might be considered as consisting essentially of Mediterranean water.

53. The experiments with the Current-drag were commenced at $2\frac{1}{2}$ hours after High water, when the ebb-tide was running eastwards. The current on the surface was running inwards at the rate of 1·25 mile per hour; and this was also found to be its rate at 25 fathoms depth. When the drag, suspended from a small boat, was lowered to 100 fathoms, it still moved to the *eastward*, but at a slower rate; the *surface*-current passing the boat at the (estimated) rate of 0·25 mile per hour. The drag being then lowered to 119 fathoms, and suspended from a buoy, it first moved *eastwards* at the rate of 0·18 mile per hour; and then at Low water, while the *surface*-current was still moving *east*, it began to move *westwards*, retarded at first by the action of the *surface*-current on the floating buoy. At 1 hour after Low water, the *surface*-current having stopped running, the current-drag had drifted 0·18 mile to the west; but as it was found then to have grounded in 118 fathoms, its line was shortened to 108 fathoms. It immediately ran away with its buoy to the *westward*, drag-

ging it fast through the surface-water, which was itself setting in the same direction, against a light west wind; and its rate, at $2\frac{1}{2}$ hours after low water, was estimated at 1·2 mile per hour, that of the surface being estimated at 0·5 mile per hour.—Thus it appeared that in this situation both the upper (Atlantic) current and the lower (Mediterranean) current followed the *direction* of the Tidal movement, and that their *rates* were greatly affected by it; but a comparison of the *relative amounts* of the flow in each case showed a decided excess in the movement of the *upper* current to the *eastward*, and a no less decided excess in the movement of the *under-current* to the *westward*. For taking $2\frac{1}{2}$ hours after each turn of the tide as the time of greatest velocity of each current, the comparison of estimated rates (§ 60) stands thus:—

$2\frac{1}{2}$ hours after L. W.

$2\frac{1}{2}$ hours after H. W.

Surface-current W. $\leftarrow$ 0·5 mile per hour. $\rightarrow$ E. 1·25 mile per hour.

Under-current W. $\leftarrow$ 1·2 mile per hour. $\rightarrow$ E. 0·88 mile per hour.

Thus the excess of *inflow* of the *upper* current being at the rate of 0·75 mile per hour, that of *outflow* of the *under-current* was 0·32 mile per hour.

54. Having then proceeded to Gibraltar, our first day's work (Aug. 26) at the Mediterranean end of the Strait was chiefly devoted to experiments with Mr. Siemens's Photometric apparatus; the results of which, as they were not altogether satisfactory, I think it better not to record. But the opportunity was taken to obtain a series of Specific Gravities at different depths in mid-channel between Europa Point and the African coast. A strong easterly wind was blowing through the day, raising a considerable swell; and this had an obvious effect on the Sp. Gr. of the upper stratum, which showed a decided admixture of Mediterranean water with the Atlantic water properly forming it; for instead of the 1·0271, which we had found last year in this situation when a moderate westerly wind was blowing, the Sp. Gr. of the surface-water proved to be 1·0277; at 100 fathoms it had increased to 1·0279; and the same Sp. Gr. was found at 200 fathoms. At 250 fathoms, however, as in the two observations made in the former year at the same part of the Strait, we came upon unmistakable Mediterranean water, its Sp. Gr. being 1029·5; this showed itself again at 300 fathoms, and again in water taken from the bottom at 480 fathoms. Notwithstanding, therefore, the unusually high Sp. Gr. of the upper stratum, the slightness of the increase down to 200 fathoms, and the marked increase encountered between 200 and 250 fathoms, clearly showed that its character was essentially Atlantic; and thus we had distinct evidence that the Mediterranean stratum here lies *at least 200 fathoms from the surface*. It was further interesting to remark that the *whole* of the lower stratum was composed of *densest* Mediterranean water; whereas in two observations made last year at an interval of six weeks, the water at the bottom was found to be of *less* Sp. Gr. than the water at 250 fathoms. It thus appears that in this peculiar channel considerable changes may

be produced, even at a depth of from 400 to 500 fathoms, by the action of Winds and Tides.

55. On the 28th of August we proceeded to make a series of experiments with the Current-drag in the deep water off Point Cires on the African side; first, however, making a series of observations on the Specific Gravity of the water at different depths, for the purpose of ascertaining the position of the plane of separation between the two strata. This was very clearly indicated as lying between 200 and 225 fathoms; for while the Sp. Gr. of the surface-water was 1·0279 (being evidently raised by the westerly drift of Mediterranean water, kept up by the continuance of a strong East wind), and that of the water at 200 fathoms was 1·0283, the Sp. Gr. at 225 fathoms was 1·0298, and at 250 and 300 fathoms it was 1·0296. The continued strong East wind (force 6) obviously had a decided effect in retarding the *surface-current*, which, as the tide was ebbing during the whole series of observations, would probably have set very strongly to the eastward (it being near the date of full-moon) but for this opposing influence. The *under-current*, on the other hand, flowed *eastwards* during the same ebb at a rate in the first instance *exceeding* that of the surface-current, though subsequently *much less*, as is shown in the following Table:—

Time.	SURFACE-CURRENT.		UNDER-CURRENT.	
	Rate per hour.	Depth.	Rate per hour.	
1½ to 2 hours after H. W.	1·0 mile.	225 faths.	2·6 miles.	
2½ " " "	2·0 miles	300 "	2·4 "	
3 " " "	3·8 "	50 "	3·8 "	
3½ " " "	4·4 "	100 "	2·6 "	
4 " " "	—	150 "	1·9 "	
4½ " " "	3·3 "	225 "	1·4 "	

It thus appeared (1) that the influence of the ebb on the under-current was exerted earlier and more strongly than on the upper current, the former at first moving eastwards at the rate of 2·6 miles an hour, whilst the rate of the latter was only 1 mile; but (2) that at a more advanced period of the ebb the relative rates were reversed, that of the surface-current having increased to 4·4 miles an hour, and being still 3·3 miles when the drag, hanging at the same depth (225 fathoms) as in the first observation, showed a movement of the under-current of only 1·4 mile.—This suggests the question whether the rapid flow of the Under-current on this occasion *towards* the east may not—anomalous as the fact may seem—have been really due to the strength of the wind blowing *from* the east. For, as was pointed out by Sir Wm. Thomson and Prof. Stokes, in the discussion which took place on a paper which I submitted to the Mathematical and Physical Section at the Edinburgh Meeting of the British Association*, when a strong wind continues to blow *into* a loch or long narrow inlet, it

* See 'Nature,' Aug. 17, 1871, p. 316.

raises a "head" of water, the pressure of which must produce an *outward* Under-current; as is evidenced by the *continuance* of the surface in-current, which would otherwise cease as soon as the rise of the water is sufficient to neutralize by excess of gravity the force of the wind. Now here, although the westerly drift produced by the wind is not antagonized by the direct obstacle of a land-barrier, yet the strong in-current which meets it will obviously have the like tendency to raise a "head" of water, especially in that narrowest part of the Strait which lies between Tarifa and Point Alcazar; and the increase of pressure produced by this, acting in the direction of the Tidal movement of the under-current, would obviously tend to accelerate it.

56. With the view of obtaining another set of observations on the deeper (southern) part of the "ridge," we proceeded thither during the night, and took up our position, on the morning of the 29th, about 7 miles W.S.W. of Cape Spartel. There was a slight Westerly wind, with a smooth sea. The Specific Gravity of the surface-water, taken 2 hours after low water, when the flow of the tide was giving a westerly movement to both strata, was 1.0275; thus showing, by its excess above the ordinary standard of Atlantic water, that the surface-drift from the Mediterranean produced by the continuance of strong Easterly wind had reached this end of the Strait. The Sp. Gr. at 130 fathoms was 1.0282, at 155 fathoms it was 1.0284, and was the same on the bottom at 180 fathoms. Thus it appeared that as the lower stratum here consists of a *mixture* of Mediterranean and Atlantic water, the predominance of the outward under-current is not indicated so strongly by Sp. Gr. as it is on the shallower (northern) part of the ridge, where the lowest stratum consists of nearly *pure* Mediterranean water (§ 52).—The results of this day's experiments with the Current-drag confirmed the conclusion indicated by the previous series, as to the complete Tidal reversal of both currents at this end of the Strait; whilst they gave even stronger evidence of the excess of *inward* movement in the upper stratum, and of *outward* movement in the lower. From 2 to 5 hours after Low water, the *surface*-current was running *westwards* at the rate of 0.75 mile; it then slackened, became stationary at High water, and then flowed *eastwards*, its rate increasing at $3\frac{1}{2}$ hours after High water to 1.2 mile per hour. On the other hand, the *under*-current at $3\frac{1}{2}$ hours after Low water was shown, by a drag hung at 155 fathoms depth, to be flowing *westwards* at the estimated rate of 1.25 mile per hour, and from $3\frac{1}{2}$ to $4\frac{1}{2}$ hours was still running at the rate of 1.10 mile; whilst at from 3 to $3\frac{1}{2}$ hours after High water it flowed *eastwards* at the estimated rate of only 0.67 mile per hour; the excess of *inflow* of the *upper*-current, and that of *outflow* of the *under*-current, being thus each 0.45 mile per hour.

3 hours after L. W.

3 hours after H. W.

Surface-current W. $\leftarrow$ 0.75 mile per hour. $\rightarrow$ E. 1.20 mile per hour.
Under-current W. $\leftarrow$ 1.12 mile per hour. $\rightarrow$ E. 0.67 mile per hour.

57. On the 30th of August (Full Moon) the ship was taken into the

position occupied on the 28th; with the view of experimenting in the narrow part of the Strait for as long a period of the *flood*-tide as possible, so as to compare the results with those previously taken during the ebb. The wind was here still from the East, with a force of from 3 to 4. A *surface*-current-drag having been put over very soon after Low water, it drifted at first nearly due South, or *across* the channel, but in the second and third hours changed its course to the S.W., moving at the rate of 1·6 and 1·5 mile per hour. Having got into the in-shore current near the African side, the drag was then taken up and started afresh in the middle of the Strait, close to the under-current-drag; and it then, between 4 and 5 hours after Low water, drifted W.S.W. at the rate of 0·55 mile per hour. At High water, the surface-drag became stationary, and soon after commenced drifting to the eastward. As the wind freshened at the same time to a force of 6, the surface-drag was taken up; but the drift of the ship during the rest of the ebb-tide denoted a strong east-running surface-current. The direction of the *under*-current, as indicated by a current-drag at 250 fathoms depth, was very decidedly *westward*, while the surface-buoy was moving nearly due south; and its rate at $2\frac{1}{2}$ hours from the beginning of the ebb was estimated at 1·8 mile per hour. At from 3 to 4 hours after low water, the rate of the *westward* under-current was 1·6 mile; at from 4 to 5 hours it was still 1·25 mile; and between 5 hours and high water it was 0·8. The direction of the under-current changed at High water; and at 1 hour afterwards it had acquired an *eastward* rate of 1·0 mile, which increased to 1·6 at 2 hours after H. W., its *inward* rate thus approaching to an equality with its *outward* rate during the flood, which may not improbably have proceeded (as on the 28th) to an absolute excess.—It may fairly be questioned, however, whether the strength of this *easterly* Under-current during the ebb was not to be attributed (as already suggested) to the continuance of the strong Easterly wind, which by heaping up the surface-water, would augment the downward pressure on the under-stratum. It is considered by Capt. Nares, whose judgment on such a point is entitled to great weight, that the observations made at the Mediterranean end of the Strait are not by any means so satisfactory as those made on the "ridge" at the Atlantic end; since "the eddies" which would naturally be expected at this part, in consequence of the "funnel-shaped mouth of the Strait, complicate the movements and prevent" such exact demonstrations as those found further to the westward, where "the current-stream runs more steadily."

58. Giving our chief attention, then, to the phenomena presented at the Western extremity of the Straits, we find these to be as follows:—

I. There is a reversal, with every ebb and flow of the Tide, in the direction alike of the *upper* and of the *under*-current: but while the *under*-current is the stronger during the *flood* or *outgoing* tide, the *upper* current is the stronger during the ebb or *ingoing* tide; and while the balance of the *outward* and *inward* movement during each tide is decidedly *inwards*

in the *upper* current, it is decidedly *outwards* in the *under*-current (§§ 53, 56).

II. The *upper* stratum here always consists of nearly unmixed Atlantic water; showing that the westerly flow which takes place during the ebb is insufficient to bring Mediterranean water from the opposite end of the Strait. The increase sometimes observable (§§ 51, 54) in the Sp. Gr. of the surface-water of the Strait appears attributable rather to wind-drift than to tidal movement.

III. On the other hand, the *under* stratum here (as at the opposite end of the Strait) either consists entirely of *Mediterranean* water, or shows a large admixture of it; and as this is the case alike during the *inward* and the *outward* movement of the under stratum, it seems obvious that Mediterranean water must extend some distance to the westward,—since, if it merely came up to the “ridge” without crossing it, the tidal inflow would replace it by Atlantic water. And this inference is confirmed by the fact that an admixture of Mediterranean water is distinctly traceable far into the Atlantic basin (§ 49).

IV. The stratum of Mediterranean water which is found at a depth between 100 and 125 fathoms on the “ridge” (§ 52) must be derived from the stratum which, in the deeper part of the Strait (extending westward as far as Tarifa), lies at more than 200 fathoms from the surface. Hence the lower or Mediterranean stratum must form an inclined plane from Tarifa to the “ridge,” the surface of which is about 100 fathoms higher at its western than at its eastern end; and as the distance between these two points is about 15 miles, the gradient will be about $\frac{100 \text{ fathoms}}{15 \text{ miles}}$

or about 1 in 132. But it must be remembered that we have not here to do with the *absolute weight* of this body of water, but only with the *difference* in Sp. Gr. between water of (say) 1·027 and water of 1·029; which is less than 1-500th part of the absolute weight of the water which thus runs up-hill. And with the evidence we have in the Florida Channel (§§ 129–133) of the passage of the denser because colder water over the shallowest part of the Narrows, there is no improbability in the like flow of the denser because more saline water over the marine watershed which separates the Mediterranean from the Atlantic basin, if there be a predominant westerly movement in the under-stratum. But if there were no such movement,—the under-stratum being either at rest, or its flux and reflux being equal,—there seems no reason why this inclination of its surface should be maintained against the operation of Gravity, which will be constantly tending to bring it to a level.

59. I venture, therefore, still to maintain that the existence of a Tidal flux and reflux in the Gibraltar currents does not prove that they are entirely sustained by tidal action; any more than the existence of an alternate ebb and flow in a river proves that there is no down-flowing stream. In every tidal river, the ebb is stronger on the whole than the

flood; the excess being proportional to the amount of fresh water which the upper part of the river brings down. And thus it happens that a floating body thrown into such a river is at last carried out to sea, though it may have been brought back by the tide twenty, fifty, or a hundred times, each time stopping at a point a little further down than before. Now there can be no doubt whatever, that, putting the action of Wind out of the question, a vessel which enters the Western end of the Strait would be gradually carried into the Mediterranean by the predominant *easterly* movement of the *upper* current; though its general easterly progress would be interrupted by a succession of returns to the westward, or, when there might be no actual return, by periods of rest. And the evidence appears to me just as conclusive, that if a body could be so weighted as to remain freely suspended in the Mediterranean stratum off Gibraltar, and its movements could be watched from above, we should find it in like manner gradually working its way towards the opposite end of the Strait, and at last clearing the "ridge" to descend along the Atlantic slope beyond. This it could not do unless the Tidal action were supplemented by an out-flow produced by some other agency; and such an agency exists in the excess of lateral pressure in the Mediterranean column above that of the Atlantic column, which is proportional to the excess of the Specific Gravity of Mediterranean water.—In the strong continuous Under-currents whose existence in the Dardanelles and in the Baltic Sound has now been conclusively established, we see what larger differences in Specific Gravity, uncomplicated by Tidal action, can effect. (See Appendix II.; also § 134.)

60. In one respect it appears to me that the Specific Gravity observations,—by which it can be certainly determined whether the water at any given depth is Atlantic, Mediterranean, or a mixture of the two,—are more satisfactory than those made by the Current-drag. For the *actual* movement of the drag can only give the *real rate* of movement of the stratum in which it is hanging, when that rate is the same as that of the surface-stratum in which the suspending buoy is floating; in which case there will be no *pull* of the buoy upon the drag, or of the drag upon the buoy (see Appendix II.). If the *under-current* be flowing faster than the upper, the drag will be kept *back* by the buoy; whilst if the *surface-current* be flowing faster than the deeper stratum, the drag will be pulled *onwards* by the buoy. If, again, the two strata be moving in opposite directions, the reciprocal influence of the drag and the buoy will make the *observed* rate still more different from the *real* rate, and perhaps will even render both *stationary*. Hence the *actual* rate of the under-current can only be *estimated* from the observed rate of movement of the suspending buoy; and the rule adopted by Capt. Nares in making such estimates was to halve the difference between the observed rate of the suspending-buoy and that of the surface-current, and to *add* this half to the former when the rate of the under-current was the greater, *deducting* it when the rate of the surface-current was the greater. Thus when the surface-current was running at 1·0 mile an hour,

and the buoy moved in the same direction at the rate of 1·35 mile per hour, the real rate of the under-current was estimated at $1·35 + 0·17$, or 1·52 mile per hour. On the other hand when the surface-current was running at 4·4 miles per hour, and the buoy moved in the same direction at the rate of 3·2 miles per hour, the real rate of the under-current was estimated at $3·2 - 0·7$, or 2·5 miles per hour.

61. In the event of any renewal of such experiments, either in the Strait of Gibraltar or elsewhere, I should recommend that the relative resistances of the Current-drag and of the Suspending-buoy at different rates of movement should be tested, in the first instance, by drawing them separately through still water with a Dynamometer attached to the line; and further, that by suspending the current-drag at different depths, and by testing the resistance then offered in each case by the drag and the line conjointly, the amount due to the latter should be determined by the elimination of the former. If in this manner the amount of resistance that is offered by (say) every 20 fathoms of the line from which the drag is suspended be ascertained, we shall have satisfactory data for determining, with a near approach to accuracy, the actual rate of the current in which the drag is suspended. For as it may be pretty certainly determined by Specific Gravity observations to what depth the upper stratum extends at the point of observation, it will be easy to compute, on the one hand, the force exerted by its current upon the suspending-buoy and on the upper part of the line that hangs from it; and, on the other, the force of the under-current, not only upon the drag, but upon the portion of the suspending line that hangs in it: and from these data the *actual rate* of the under-current can be readily worked out with a near approach to accuracy.

62. *Temperature of the Strait of Gibraltar.*—It will be remembered that in the previous year's work a marked reduction of Temperature was observed in the mid-stream of the Strait, as compared with the water nearer the Spanish side; and the inference drawn from these observations was, that "either the water of which the in-current consists is drawn from "a part of the Atlantic at least as far north as Lisbon, or that it is derived "from a stratum of the neighbouring ocean somewhat beneath the surface, "so as to have received less of the solar superheating than the actual surface- "water" (Report for 1870, § 74). On the other hand, the excess of temperature in the surface-water of the northern side of the Western *embouchure* of the Strait was considered as indicating that there is a predominant surface-outflow of Mediterranean water along the Spanish coast; a fact, I was informed, well known to those who have navigated it (§ 75).—Being desirous of obtaining further information on this point, I requested Capt. Nares to take observations of surface-temperature at short intervals, on the two occasions on which we were running obliquely across the Strait. One of these series (I.) extends along a line of about 10 miles from the neighbourhood of the Pearl Rock, at the entrance of Gibraltar Bay, to a short distance west of Point Cires on the African Coast; the other

(II.) from Tarifa to the eastern entrance to Tangier Bay, a line of about the same length, but about ten miles further west:—

I.		II.		III.	
Pearl Rock	72½° Fahr.	Tarifa	67° Fahr.	Cape Spartel	68° Fahr.
"	70½	"	66	"	68
"	68½	"	64	"	65
"	65½	"	63	"	64
"	62	"	62	"	63
"	60	"	62	"	63
"	59	"	63	"	64
"	60	"	62	"	62½
"	60	"	62	"	62
Point Cires	59½	Tangier Bay	60½	Tangier Bay	60½

Besides these, another Series (III.) was taken along the African coast, between a point a little to the west of Cape Spartel and the western entrance of Tangier Bay. And other observations taken to the S.E. of Europa Point gave temperatures of 72° and 71°·5, which corresponded with those obtained last year near the entrance of the Mediterranean, its proper temperature being here somewhat reduced by the inflow of colder water through the Strait (Report for 1870, § 77).—Hence it appears that whilst the water nearest the Spanish coast in Series I. had the temperature of the Mediterranean, there was a rapid fall in the thermometer as we came into the mid-stream, and a still further reduction occurred towards the African side,—the lowest temperature observed being 13°·5 beneath the highest, simply in changing our place a few miles to the southward. At Tarifa the influence of the Mediterranean temperature was less marked; but the temperatures taken near the African side within the embouchure of the Strait were nearly as low as in Series I.

63. I learn from Dr. Hooker, who has lately visited Morocco, that the prevalence along that coast of a temperature decidedly below that of the opposite coast of Spain, is a fact which has long been known locally; and that it is indicated at present by the character of the Flora, whilst a still more marked reduction in past times is marked by the Boreal character of the Shells found in the later Tertiary deposits. Looking to the fact that a general *southerly set* is traceable in the water of this part of the Atlantic,—partly produced, it would appear, by predominant northerly wind-drift, and partly by the indraught requisite to supply the westerly Atlantic drift produced by the Trade Winds (§ 120),—I am disposed to think that the lower temperature of the Gibraltar in-current is due to its original derivation, not from the portion of the Atlantic immediately outside it on the same parallel, but from an area of lower surface-temperature to the north-west. But it seems at the same time not improbable that just as the water which flows over a mill-dam is drawn, not so

much from the surface-stratum, as from a stratum a little below it*, so the current which is (as it were) sucked-in through the Strait to supply the excess of evaporation in the Mediterranean should be drawn from a sub-surface stratum, and should thus bring with it a lower temperature.

64. On our entrance into the Mediterranean, we kept in the first instance along the African coast, and took frequent observations of surface-temperature; but we found that we soon lost all indication of the depression observed within the Strait, the thermometer never falling lower than 70° ; so that this cold in-current speedily loses its peculiar character by mingling with the general body of Mediterranean water.

PART III.

PHYSICAL RESEARCHES IN THE MEDITERRANEAN.

65. *Temperature*.—The Temperature-phenomena of the *Eastern* basin of the Mediterranean were found to correspond in all essential points with those previously determined in the Western. The limitation in the thickness of the stratum superheated by direct insolation, and the almost exact uniformity of temperature beneath this stratum down to the greatest depths, are features no less characteristic of the former than of the latter, —being, in fact, yet more remarkable in the circumstance that the range of depth in the Eastern basin is about 500 fathoms greater than in the Western, some parts of its bottom lying at nearly 2200 fathoms depth from its surface. But certain differences were also noted which are sufficiently important to deserve being stated in detail.

66. It should be mentioned, in the first place, that the heat of the latter part of September 1871 was felt at Malta to be peculiarly oppressive, the temperature of the air occasionally rising to 90° , and that of the sea to 80° ; and that this high temperature did not suffer much reduction as we proceeded towards Egypt during the first fortnight of October. On the 3rd of that month, in Lat. $35^{\circ} 54'$ N. and Long. $16^{\circ} 23'$ E., the surface-temperature of the sea was still 80° ; and on the 11th, in Lat. $32^{\circ} 17\frac{1}{2}'$ N. and Long. $26^{\circ} 44'$ E., it was 79° : at the former of these stations the *bottom*-temperature at 1650 fathoms was 56° ,—thus corresponding exactly with the bottom-temperature which we obtained last year at 1743 fathoms (in Lat. $36^{\circ} 31'$ N. and Long. $15^{\circ} 46'$ E.) a little to the east of Malta,—and at the latter it was $56^{\circ} \cdot 7$ at 1970 fathoms.

67. A *series* of Soundings was made (at my request) by Capt. Nares at each of these Stations, for the determination of the Temperature at successive intervals of 10 fathoms, from the surface down to 100 fathoms; and below this at intervals of 50 fathoms, until the depth should be reached at which the temperature becomes uniform down to the bottom. The results of these soundings are given in Columns III. and IV. of the

* See Maury's 'Physical Geography of the Sea,' § 387.

following Table, in correlation with those of two sets of serial soundings (Columns I. and II.) taken last year in the Western basin :—

Summer Temperature of the Mediterranean, as shown by Serial and Bottom-Soundings.

	Western Basin.				Eastern Basin.			
	I.		II.		III.		IV.	
	Lat. 36° 0' N. Long. 4° 40' W.		Lat. 35° 59' N. Long. 5° 55' E.		Lat. 35° 54' N. Long. 16° 23' E.		Lat. 32° 17½' N. Long. 26° 44' E.	
	De- grees Fahr.	Reduction below Surface.	De- grees Fahr.	Reduction below Surface.	De- grees Fahr.	Reduction below Surface.	De- grees Fahr.	Reduction below Surface.
Surface	74·5		77·0		80·0		79·0	
10 fath. ...	69·3	5·2	71·0	6·0	76·2	3·8	76·0	3·0
20 " ...	65·0	9·5	61·5	15·5	72·6	7·4	76·0	3·0
30 " ...	63·0	11·5	60·0	17·0	66·2	13·8	75·5	3·5
40 " ...	61·7	12·8	57·3	19·7	63·5	16·5	69·0	10·0
50 " ...	59·7	14·8	56·7	20·3	61·0	19·0	67·0	12·0
60 " ...	...	...	...	...	59·7	20·3	65·5	14·5
70 " ...	...	...	...	...	59·2	20·8	61·8	17·2
80 " ...	...	...	...	...	58·8	21·2	61·0	18·0
90 " ...	...	...	...	...	58·5	21·5	59·8	19·2
100 " ...	55·1	19·4	55·5	21·5	58·5	21·5	59·5	19·5
150 " ...	...	...	...	...	58·0	22·0	59·5	19·5
200 " ...	...	...	...	...	56·5	23·5	58·5	20·5
300 " ...	...	...	...	...	...	...	57·0	22·0
400 " ...	...	...	...	...	...	...	56·0	23·0
500 " ...	...	...	...	...	...	...	57·0	22·0
586 " ...	55·0	19·5	...	...	...	...	...	...
1456 " ...	...	...	55·0	22·0	...	...	...	...
1650 " ...	...	...	...	...	56·0	24·0	...	...
1970 " ...	...	...	...	...	...	...	56·7	22·3

These results are also graphically expressed, as regards the superficial stratum, by the Curves in Diagram II., Plate IV.

68. Now it will be observed that in these four Series the rates of descent are by no means in accordance with each other, the differences between the first three, however, being much less than between any one of them and the fourth. The nearest resemblance is that which exists between Nos. I. and III.; for although the surface-temperature is $5\frac{1}{2}^{\circ}$ higher in the latter, the rates of reduction at successive depths so nearly correspond, as to give the two curves a general parallelism; the temperature in No. III. at 100 fathoms being still $3^{\circ}\cdot 4$ above the temperature at the same depth in No. I. But while in No. I. the temperature exhibits no further reduction down to the bottom at 586 fathoms, it falls 2° between 100 and 200 fathoms in No. III., so as to come down to within little more than a degree of the temperature of the constant stratum in No. I., and

nearly the whole of this excess it retains to the bottom at 1650 fathoms. The rate of reduction in No. II. differs from the preceding in being much *more* rapid between 10 and 20 fathoms; the reduction in that stratum being $9^{\circ}5$, as against $4^{\circ}3$ in No. I., and $3^{\circ}6$ in No. III. And this depression extends to the subjacent strata; the temperature falling almost to its minimum at 50 fathoms. On the other hand in No. IV. the temperature of the upper stratum shows a much *less* rapid reduction than in either No. I., II., or III.; the high surface-temperature being carried down to 30 fathoms with a loss of only $3\frac{1}{2}^{\circ}$. Between 30 and 40 fathoms, however, the reduction is more considerable, amounting to $6\frac{1}{2}^{\circ}$; but from this depth to 60 fathoms, the temperature is still about six degrees higher than at the like depth in No. III.; and whilst at 60 fathoms the temperature in No. III. is only $3^{\circ}7$ above that of the bottom, it is $8^{\circ}8$ above that of the bottom in No. IV. Whilst in No. III., however, the further reduction takes place very slowly, so that the temperature only falls $1^{\circ}2$ between 60 and 100 fathoms, there is a fall of 6° in this stratum of No. IV., which brings down the temperature at 100 fathoms to within one degree of the temperature at the same depth in No. III. A slight excess appears to be maintained at yet greater depths; the temperature at 200 fathoms being 2° higher in No. IV. than in No. III., and being still $1^{\circ}8$ higher in No. IV. than the temperature of the bottom, whilst in No. III. it is at that depth only $0^{\circ}5$ higher; and the bottom-temperature of No. IV., even at a depth of 1970 fathoms, was $0\cdot7$ in excess of the bottom-temperature of No. III. at 1650 fathoms.

69. It would thus appear:—(1) that the high surface-temperature which we met with during the early part of October, in proceeding from Malta to Alexandria, extended to a much greater depth in Long. $26^{\circ}44'$ E. than it did in Long. $16^{\circ}23'$ E.; (2) that the stratum of which the temperature is considerably raised by insolation was much thicker at the former than at the latter station; and (3) that the temperature of the stratum between 100 and 200 fathoms still exhibits in the Eastern basin some evidence of being influenced by direct insolation, the bottom-temperature which is met with in the Western basin at all depths below 100 fathoms being here not encountered until 200 fathoms have been passed.

70. How far these differences are due to the different conditions of the Eastern and Western basins, or are attributable to the remarkable prolongation of a high Summer temperature in the season of 1871, is a point which can only be determined by a much more extended series of observations. There are, however, some considerations which may help us to a probable conclusion.—In the first place, it appears certain that a higher *surface*-temperature prevails over the Eastern basin generally than over the Western. This is doubtless partly due to its lower Latitude; for whilst the axis of the Western basin may be considered to correspond with the parallel of 38° , that of the Eastern corresponds with the parallel of 34° . But what has probably a yet greater effect, is the absence along the Eastern portion

of North Africa of any mountain-barrier like that of the Atlas and other ridges which intervene between the Sahara and the coasts of Morocco and Algeria, and cool down those heated winds which blow from Central Africa without any moderating influence over the low expanse of Tripoli and Egypt. And further, while the surface-temperature of the Western basin is also kept down by the admission of colder water through the Straits of Gibraltar, that of the Eastern basin will be elevated rather than depressed by the discharge of the vast body of water brought down by the Nile through the hottest months of the year. And thus it comes to pass that the summer isotherm of 80° which runs through the interior of Northern Africa from Mogador to the Syrtis, thence follows the coast-line between Tunis and Syria, then turns northwards along the coast of Syria, and returns along the coast of Asia Minor, so as to enclose the Levant in a "bight" of high temperature.—Looking, again, to the fact that the *bottom*-temperature was found in the previous year to be somewhat higher, even in the Western basin, to the east of Sardinia, than nearer the Strait of Gibraltar, I think it probable that the permanent bottom-temperature of the whole Eastern portion of the Mediterranean is about 2° higher than that of the Western. The cause of this difference, also, is to be sought in the conditions which affect the surface-temperature; for, as I showed in my last year's Report (§§ 88–91), the complete separation between the deeper water of the Mediterranean and that of the Atlantic will cause the temperature of the former to be the *lowest mean* of the locality; and thus as the *winter* surface-temperature of the Eastern basin is somewhat above that of the Western, its *bottom*-temperature also will be higher. A remarkable confirmation of this view is afforded by the fact already stated respecting the temperature of the Gulf of Suez (§ 11).

71. It might be anticipated, therefore, that such an excess of temperature in the whole superficial stratum heated by direct insolation would show itself in the Eastern basin, as is represented by Series III. (Table and Diagram) when compared with Series I. and II. But the extraordinary elevation shown in the superficial stratum of No. IV. seems to betoken some special calorifying agency; for although the difference of about $3\frac{1}{2}^{\circ}$ of Latitude in favour of that Station might account for a general elevation, yet as this does not show itself at all in the *surface*-temperature, and scarcely at all in the *bottom*-temperature, there seems no reason for its showing itself to such a marked degree in the *intermediate* temperatures,—especially in those of 20 and 30 fathoms. Now if I was correct in the interpretation which I gave, in my last year's Report (§§ 90, 91), of the mode in which the Sun's heat penetrates downwards by *convection*,—the surface-films successively concentrated by evaporation sinking until their excess of density is lost by diffusion,—it is obvious that the longer the continuance of surface-heat, especially if combined with dryness, the deeper would its influence extend, though the surface-temperature might not itself be raised. For, as I then remarked, "the continual repetition of this process

“through the hot season will carry the elevation of temperature further and further down; but so soon as the temperature of the Air falls much *below* that of the Sea, the surface-layer being cooled will become heavier and sink, and will thus carry down *cold* instead of heat.” Now as Series IV. was taken not merely eight days later than Series III., but also considerably nearer to the northern coast of Africa, from which a hot dry wind was continually blowing, I am inclined to believe that this remarkable downward extension of a temperature as high as the mean between the surface-temperatures of Nos. I. and II. is attributable to these accidental influences, the local effect of which would be very little interfered with in this part of the Mediterranean by any horizontal movement of water,—neither tides nor currents having any considerable force along the Tripoli Coast.—It may be hoped that as Serial temperature-observations down to 100 fathoms can be made with very little difficulty or expenditure of time, such observations may be systematically prosecuted in different parts of the Eastern basin, so that it may be ascertained what are the conditions by which the rate of reduction of temperature from the surface downwards is determined.

72. *Density of Water*.—It might be anticipated that a higher density would prevail in the Eastern basin of the Mediterranean than in the Western, for two reasons:—first, that the hot and dry winds of the Libyan desert, unchecked and untempered by the interposition of any mountain-range, would produce a greater evaporation from its surface; and second, that the reduction produced by the inflow of Atlantic water would scarcely operate at so great a distance. Accordingly the analyses of Prof. Forchhammer gave a larger proportion of saline matter in the water to the eastward of Malta; and my own determinations of Specific Gravity lead to the same result. These observations, which were frequently repeated upon surface-water as we proceeded eastward from Malta, did not at first indicate any decided increase in density; for in the previous year (Report for 1870, § 92) we had found the Sp. Gr. of the surface-water in the neighbourhood of Sicily to average 1·0280, sometimes rising as high as 1·0284; whilst between Malta and Crete we now found it to vary between 1·0284 and 1·0288. The Sp. Gr. of the sample brought up by the water-bottle from the depth of 2000 fathoms, in the Sounding taken on the 3rd of October about 100 miles to the east of Malta, was 1·0291; thus being slightly in excess of that of the surface-water, which was 1·0288. In the deep Sounding taken eight days afterwards, not far from the Gulf of Solloom on the Libyan coast, the density was found still greater; the Sp. Gr. of the bottom-water obtained from a depth of 1650 fathoms being 1·0294, while that of the surface-water was 1·0293. In another Sounding taken on the following day nearer the coast of Africa, the density of the bottom-water at a depth of 365 fathoms was found to be much more in excess of that of the surface-water; the Sp. Gr. of the former being 1·0302, while that of the latter was only 1·0294. These results agreed in a very marked manner

with those obtained last year in the Western Basin (Report for 1870, § 94), as to the fact of the difference in Salinity between the surface- and bottom-water being greatest where the depth is moderate; and the fact of course becomes yet more significant when the general increase of Salinity is so marked. There appears, then, no reason to doubt the explanation offered last year; viz. that supposing an equal degree of concentration by surface-evaporation to take place in two or more equal areas, the elevation of the Sp. Gr. of the entire column of underlying water will be inversely proportional to the height of that column: for the diffusion of equal amounts of concentrated water through columns whose heights are in the proportion of 1, 2, 3, will raise the Sp. Gr. of these columns respectively in the proportion of 3, 2, 1; the *shortest* column being *most* affected, while the *longest*, in which the same amount of concentrated water is diffused through three times the quantity, has its density but little raised.

73. *Nature of Bottom.*—The character of the bottom indicated by the two deep Soundings which we took in the Eastern basin, corresponded with that which was ascertained last year to prevail in the deeper part of the Western,—the samples of the deposit brought up by the Sounding-apparatus showing it to consist entirely of clayey mud composed of particles in a state of extremely minute division, and the water brought up by the water-bottle from the stratum immediately overlying the bottom being rendered turbid by the presence of like finely divided particles in suspension. Mud of a similar character has been almost universally found by Capt. Spratt* and Capt. Nares (both of whom have been engaged in surveying the Eastern Basin of the Mediterranean) at depths exceeding 250–300 fathoms; sometimes, however, containing minute Foraminiferal shells. A careful examination of the two samples just alluded to gave no trace either of Foraminifera or of any other Organic forms; and as it is only in comparatively shallow waters that such traces are met with, I am inclined to believe that wherever they occur they must have been derived from such a littoral bottom as we found along the Tripoli coast, where Foraminifera abounded at depths of from 100 to 150 fathoms.—The material of the muddy deposit on the bottom of the Eastern basin must probably be for the most part derived from the Nile; and that it should have exactly the same character near the western border of the basin as it has in much closer proximity to the mouths of that river, is a striking indication of the enormous amount of such material which must be brought down by its current, and of the length of time required for the subsidence of the most finely divided particles.

74. In my last year's Report (§§ 100–103) I laid great stress upon the slow subsidence of the sedimentary particles, and the turbidity of the bottom-water which is thus produced, as possibly accounting for the scantiness of Animal life on the deep-sea bottom of the Mediterranean; and I threw it out for the consideration of Geologists, whether the same explanation

* 'Travels and Researches in Crete,' vol. ii. p. 319.

might not apply to various cases in which there is a like scantiness of Animal remains in deposits of considerable thickness.—This view, however, has been called in question by Dr. McIntosh; who adduces, as an objection to it, that many Annelids and Nemerteans abound in muddy water, while some live nowhere else than amongst mud or muddy sand; and also that many littoral Sponges are found on extremely muddy ground, while “the Siliceous Sponges all over the world affect a muddy bottom.” “In general,” he adds, “muddy ground is found to be “much more productive in marine life of all kinds, than where the “rocks, sea-weeds, and sands are pure. Even where the margin “of the sea is rendered perfectly turbid from mud (and this, too, calcareous), as at White-Cliff Bay, in the Isle of Wight, marine animals are “abundant between tide-marks”*. None of the instances cited by Dr. McIntosh are really parallel to that of the abyssal deposit of the Mediterranean; for they are all cases of *littoral* deposit, consisting of particles very much coarser (often mixed with sand), which the tidal movement of the suspending water will keep washing-off, as much as washing-on, the respiratory surfaces. In no other part of our survey of the deep-sea bottom has there been any difficulty in clearing the water immediately overlying it by filtration. On our wonderfully rich “Holtenia-ground,” the deposit in which the Siliceous Sponges were imbedded was any thing but “muddy,” for it mainly consisted of Sand and Globigerinæ; and the water above it was free from any turbidity, save that arising from the presence of very young Globigerinæ. The whitening of the littoral water produced by the disintegration of Chalk-cliffs is not in the least degree comparable to the turbidity which results from the presence of very finely divided particles of clay; for the Calcareous particles settle down comparatively quickly, and are easily washed off again; whilst the far more minute particles of Clay are very long in subsiding, but, when they *have* been deposited, are extremely adhesive.

75. My own dredging-experience certainly does not bear out Dr. McIntosh’s statement as to the more productive character of muddy bottoms. Those who have worked at Tenby or in Lamlash Bay will be slow to admit that “purity” of the “rocks, sea-weeds, and sands” in those localities is less favourable to Marine Life than the foulness of “odoriferous mud;” though there are doubtless animals to which the latter is congenial.—The following passage from Dana’s recent Treatise “On Corals and Coral Islands” gives the experience of a very accomplished observer, acquired over a very extensive range. “The effects of sediment on growing Zoophytes are strongly marked, and may often be perceived when a “mingling of fresh water alone produces little influence. We have mentioned that the *Porites* are reduced to flattened masses by the lodgment of “sediment. The same takes place with the hemispheres of *Astræa*; and it “is not uncommon that in this way large areas at top are deprived of life.

* Annals of Nat. Hist., Jan. 1872, pp. 10-13.

"The other portions still live unaffected by the injury thus sustained. Even the *Fungia*, which are broad simple species, are occasionally destroyed over a part of the disk through the same cause, and yet the rest remains alive. It is natural, therefore, that wherever streams or currents are moving or transporting sediment, there no Corals grow; and for the same reason we find few living Zoophytes upon sandy or muddy shores" (p.121).—I venture, therefore, still to maintain that the doctrine I propounded in my former Report has not been set aside by Dr. McIntosh's facts and arguments.

76. *Gases of the Bottom-water*.—I am now disposed, however, to attribute more influence to the other condition which I suggested in my Report for 1870 (§ 103) as likely to operate prejudicially to Animal life; namely, *the stagnation produced by the almost entire absence of Vertical Circulation*. In the great Oceanic system, if the doctrine previously advocated be correct, every drop of water is in its turn brought to the surface, and exposed to the purifying influence of prolonged exposure to Atmospheric air; whereby a large proportion of its Carbonic acid and other products of the decomposition of Organic matter will be removed, and Oxygen will be absorbed in their place. But from this movement, the water of the Mediterranean may be said to be virtually excluded. The effect of the Gibraltar Currents is limited to a stratum of which the depth is very small in comparison with that of the principal area of each basin; and to whatever extent they may produce a change in the water of the deeper part of the Western basin in the neighbourhood of the Strait, it is obvious that the amount of such change must diminish as the distance increases, and that it cannot in any degree affect the water of the Eastern basin. Now, as the Nile is constantly bringing down a very large quantity of Organic matter, the finer particles of which seem to be diffused through the whole mass of the water in the basin and to be slowly gravitating to its bottom, it might be anticipated that in their gradual decomposition they would generate Carbonic acid at the expense of the Oxygen dissolved in the water; so that the abyssal water, being separated from the atmosphere by an intervening stratum of many hundred fathoms, and being never brought to the surface, would come to be unfit for the maintenance of Animal life.

77. It will be recollected that in the 'Porcupine' Expedition of 1869*, it was found that the presence of a very large proportion of Carbonic acid in the bottom-water was not incompatible with the existence of Animal life in great abundance. In fact there was reason to believe that there was a general relation of conformity between the proportion of Carbonic acid and the quantity of Animal life on the bottom as indicated by the dredge-results; the effect of the respiratory and other changes produced by the latter being to increase the proportion of Carbonic acid at the expense of the Oxygen. Thus whilst the percentage of Oxygen in *surface-water* averaged about 25 per cent., and that of Carbonic acid averaged something less than

* See "Report," pp. 483-486.

21, the Oxygen in *bottom-water* did not average above 19·5 per cent., while the Carbonic acid increased to nearly 28,—the percentage of Nitrogen being reduced at the same time from 54 to 52·5. The percentage of Carbonic acid in *bottom-water* often rose much higher than this, being frequently between 30 and 40, and in one instance more than 48; but the percentage of Oxygen did not show a corresponding reduction, being never less than 16, while that of Nitrogen came down from 54 to 34·5. Thus it appeared that *so long as Oxygen was present in sufficient proportion*, the increase of Carbonic acid to nearly half the total amount of the gases removable by boiling did not exert any unfavourable influence on Animal life; from which it might be surmised that the Carbonic acid *dissolved* in water under great pressure is in a condition altogether different from that of *gaseous* Carbonic acid as regards its relation to Animal Respiration*.

78. Having had an opportunity, in the 'Porcupine' Expedition of 1869, of making myself acquainted with the method on which the Analyses of the Gases of Sea-Water were conducted, and having provided myself on this occasion with the requisite Apparatus, I believed myself able—though not claiming to be an expert in Chemical Manipulation—to carry on similar analyses with sufficient accuracy to determine whether the condition of the abyssal water of the Mediterranean is really such as I had suspected it to be. Each of the samples taken in the two deep Soundings (§ 72) was boiled until no gas came over; and the total quantity of gas given off, which corresponded very closely with the average formerly obtained, was divided in each case into two parts, so that I had four specimens in all. The composition of these specimens agreed very closely; the percentages being approximately (for I do not pretend to minute accuracy) as follows: Oxygen 5, Nitrogen 35, Carbonic acid 60. Thus it appeared that very nearly the whole available Oxygen had been converted into Carbonic acid; so that while the proportion of Oxygen to Carbonic acid was never in the open Ocean less than *one third*, it was here no more than *one twelfth*,—a difference fully adequate to account for the paucity of Animal life on the deep bottom of the Mediterranean. That this condition does *not* extend to those moderate depths in which the water is subjected to the disturbing action of winds, tides, and currents, may be fairly presumed: but whether it prevails through the whole stratum beneath 250 or 300 fathoms, so as to constitute the essential condition by which Animal life is limited to these depths, it would obviously be premature to assert.

* It is by no means improbable that such sluggish animals as Mollusks and Echinoderms may be able to bear a much larger proportion of Carbonic acid in the water they breathe than Fishes and Crustacea. Experimental inquiries on this point, which might be readily carried out in connexion with any large Aquarium, would give results of great Physiological interest.

PART IV.

BIOLOGICAL RESEARCHES IN THE MEDITERRANEAN.

79. The Dredgings which we carried on upon the Adventure and Skerki Banks, between Sicily and the Coast of Africa, chiefly at depths between 100 and 200 fathoms, did not add any thing of importance to the collection which we made in the previous year in the same locality, save some Sponges of considerable interest. We were struck with the limitation of the areas to which particular types appeared restricted; for when encouraged by "a good haul" to put down the dredge a second time in the same locality, it frequently came up again almost empty. Whether this depended on a slight change of depth, or on the direction of under-currents, which probably have a considerable influence on these shallows, it is impossible to say. This fact, however, seemed constant,—that below 150 fathoms Animal life was extremely scanty; whilst even down to that depth *Nullipores* were often very abundant, the dredge coming up full of them. As there is no doubt of the Vegetable character of *Nullipora*, I deem this fact of considerable significance, as indicating that Light must penetrate to that depth in sufficient amount to enable this plant to decompose carbonic acid.—Our Dredgings along the African shore, though by no means unproductive, did not furnish any specimens of novel interest. Mr. Gwyn Jeffreys has kindly supplied me with the following List of the more remarkable shells obtained along the Tripoli Coast:—

BRACHIOPODA. *Platydia anomioïdes*, Scacchi.

CONCHIFERA. *Pleuronectia fenestrata*, Forbes: *Leda pygmæa*, v. Münster: *Arca obliqua*, Philippi: *Lepton nitidum*, Turton: *L. sulcatulum*, Jeffreys: *Kellia? cycladia*, S. Wood: *Axinus transversus**, Bronn: *Astarte sulcata*, Da Costa; var. *elliptica*, Brown: *A. triangularis*, Montagu; and var. *marginata* integro: *Crassatella planata**, Calcara, = *Gouldia modesta*, H. Adams: *Venus effossa*, Bivona: *Pecchiolia granulata**, Seguenza.

SOLENOCONCHIA. *Cadulus subfusiformis*, Sars.

GASTROPODA. *Scissurella crispata*, Fleming: *Rissoa cimicoides*, Forb.: *R. subsoluta*, Aradas: *R. Stefanisi*, Jeffr.: *Odostomia unifasciata*, Forb.: *O. minuta*, A. Adams: *Mesalia pusilla*, Jeffr.: *Cerithiopsis Metaxa*, Delle Chiaje: *Natica fulminea*, Risso: *Solarium discus**, Ph.: *S. Architaë*, Costa: *Trophon vaginatus*, Jan: *Pseudomurex lamellosus*, Jan: *Nassa limata*, Chemnitz; var. *nana*: *Pleurotoma torquata**, Ph.: *P. Renieri**, Sc.: *P. hystrix**, Jan: *Columbella haliæti*, Jeffr.: *Voluta pumilio*, Brusina (the Marquis de Monterosato has rightly determined this to be the very young of *Cypræa lurida*; the first whorls are exquisitely reticulated, as in *Defrancia*): *Actæon pusillus*, Forb.

Of these, the species marked * are especially interesting, because until lately they were known as fossil only.

80. The Marine Fauna of the Mediterranean, it must be borne in mind, has been carefully explored by numerous Zoologists; and the barrenness of its depths seems to leave little to be added by those explorations which have been so productive elsewhere. True it is that in the 'Porcupine' Expedition of the previous year, a dredging at 1415 fathoms depth brought up several species of Shells,—some of them of considerable interest as having been previously known only in a fossil condition (Report for 1870, § 50). But that dredging was taken in the comparatively narrow extension of the Mediterranean basin between the coasts of Spain and Africa, which is most within the influence of the Gibraltar Currents, and in which, therefore, the stagnation which I believe to exist elsewhere may be somewhat disturbed by their agency. And the fact that among these shells was a freshwater *Planorbis*, was an indication that either by gravitation or by some horizontal travelling of bottom-water (such as might be there produced by the Gibraltar under-current), the shells properly inhabiting the littoral zone might have been conveyed thither. And this view of the case is not invalidated by the fact that many of these shells are the representatives of types previously known only as fossils; since the same is true of many species found in shallow water in this extension of the Mediterranean, which seems to have been less explored than most other parts of its shores (Report for 1870, §§ 48, 49).

81. I am disposed to believe, therefore, that in the Mediterranean Basin the existence of Animal life in any abundance at a depth greater than 200 fathoms will be found quite exceptional; and that, without pronouncing its depths to be absolutely *azoic*, we may safely assert them to present a most striking contrast, in respect of Animal life, to those marine Paradises* which we continually met with in the Eastern and Northern Atlantic at depths between 500 and 1200 fathoms. And I have the satisfaction of finding that my conclusion on this point is entirely borne out by the results of the dredgings carried on in the Adriatic by Dr. Oscar Schmidt; who found the like barrenness at depths below 150 fathoms, except as regards *Foraminifera*, *Bathybius*, and *Coccoliths*†. After a most careful microscopic examination of the mud obtained from the depths of the Mediterranean, I feel justified in saying that even of these lowest organisms scarcely any traces are to be found.—Thus it appears that Edward Forbes was quite justified in the conclusion he drew *as regards the particular locality he had investigated*; and that his only mistake lay in supposing that the same conditions would prevail in the open Ocean.

82. I venture to think, however, that I have shown that the Physical conditions of any Inland Sea, which, like the Mediterranean, is cut off from the General Oceanic Circulation, must be such as greatly to modify its relation

* I use this word in the sense familiar to every Greek scholar.

† "On Coccoliths and Rhabdoliths," in Ann. of Nat. Hist., Nov. 1872, from 'Sitzungsbericht der k. k. Akad. der Wissenschaften in Wien,' Bd. lxii. (1870) Abth. i, pp. 669-682.

to Animal life; and that it is a matter of great Scientific importance, especially in relation to Geological inquiry, that these conditions should be carefully examined. The Red Sea would probably be found to present a striking contrast, in many particulars, both to the Mediterranean and to the open Ocean. Its *Thermal* condition, as I have already shown, is altogether peculiar; for while its surface-temperature rises as high as that of any Intertropical portion of the Ocean, that temperature seems to be maintained with very little reduction even to its greatest depths. Now it seems to be the universal opinion of those who have most carefully studied the existing Coral Formations, that the Reef-building Corals do not live and grow at a greater depth than 20 fathoms; and as it is affirmed by Mr. Dana, as a deduction from the Distribution of Coral Formations, that the existence of the reef-builders is *geographically* limited by the isocrymal line of 68° *, I cannot but suspect that the *bathymetrical* limit may be essentially a *thermal* one. For all we know of the relation of Temperature to Depth (§§ 3, 8) would indicate that even within the Intertropical area of the open Ocean, the temperature at 20 fathoms may not be above 68° ; and that in the next 10 fathoms it suffers considerable reduction. Now if the temperature of the Red Sea nowhere falls below 71° , it is obviously a most interesting question to determine whether the reef-building Corals are, or are not, to be found in that Sea at a greater depth than in the Oceanic area; and if so, what is the greatest depth at which they there exist. For since our own inquiries show that Stony Corals similar in physiological characters to the reef-building types can live and grow at the depth of *many hundred* fathoms, there seems to me no *a priori* reason why the latter should not thrive at like depths, if the Temperature be congenial to them.

83. The Red Sea further differs essentially from the Mediterranean, in not being the recipient of any great Rivers bringing down *detritus* from the land. This, of course, will affect the condition of the bottom; on which we should not expect to find the abundant sedimentary deposit that is everywhere settling down on the abyssal depths of the Mediterranean. It will also leave the bottom-water clear; and in this respect the condition of the bed of the Red Sea will be more favourable to Animal life than that of the Mediterranean. But the absence of *organic* sediment, if the views previously advanced be correct, will constitute a still more important difference between the conditions of the two Seas, in relation to Animal life: for while its progressive decomposition, in the abyssal water of the Mediterranean, consumes its Oxygen and imparts to it Carbonic acid, at a greater

* On Corals and Coral Formations, p. 108.—It is a very significant fact that the cold current which comes up from the south on the Western coast of South America, and which I regard as the *indraught* of the Pacific Equatorial Current (as the similar current on the Western coast of South Africa is of the Atlantic Equatorial Current, § 120), pushes the southern Isoecryme of 68° —the Coral-Sea boundary—to the north of the Equator, between the South American coast and the Galapagos, which, though under the Equator, lie outside of that boundary.

rate than "diffusion" can counterbalance without any vertical circulation in the water itself, and thus tends to render the depths of that Sea uninhabitable, the absence of the like source of impurity in the water of the Red Sea may be expected to leave its abyssal water in a condition fit to support a moderate amount of Animal life; since the process of "diffusion," even without a vertical circulation, will maintain a certain amount of interchange of gases between the superficial and the deep strata.

84. These views are *suggested* merely as fair inferences from our present very limited knowledge, to be confirmed or set aside by the results of future inquiries. I have experienced, in the course of the researches in which it has been my privilege to be engaged, so much advantage from the *clues* which have offered themselves from time to time for their guidance, that I should consider myself wanting in my duty to those who may hereafter take up the same line of investigation, if I were to be kept back from making such suggestions, by any apprehension that my personal credit would suffer from having propounded ideas which subsequent research did not bear out.—"Truth," it has been well said, "emerges out of Error, rather than out of Chaos;" and the history of Science is full of instances in which erroneous doctrines have been more *productive*, because more *suggestive*, than well-determined facts that open no access to the Unknown beyond.

ADDENDA.

As this sheet is passing through the press, I have been kindly supplied by Mr. Scott, Director of the Meteorological Department, with the following extract from a letter received from Prof. Mohn, Director of the Meteorological Institute at Christiania, giving an account of some observations recently made by him during his voyage of inspection of the Meteorological Stations on the Norwegian coast:—

"On my voyage I have taken the opportunity of making deep-sea temperature observations in the Thronthjem Fjord and the Sogne Fjord. I found exactly what I expected. You know our Fjords are deep in their middle part, and shallower at their mouth. In the deep part of the fjords the lower part of the water—say from 40 fathoms downwards—is of a constant temperature of 6° to 6°·5 Cent. [43° to 44° Fahr.]. So I found in the Sogne Fjord, 16° [61° Fahr.] on the surface, 6°·4 in 10 fathoms, and not lower than 6°·5 in different depths down to 700 fathoms. Of course the Casella-Miller's thermometer was used. This agrees with the results found by myself in the Thronthjem Fjord, and with those found in the Hardanger Fjord by Prof. Seue, and by the survey-steamer 'Hansteen' (?), Capt. Wylle. In those two fjords the constant temperature commenced in a depth of about 40–50 fathoms, and was six degrees and some tenths Centigrade. Lieutenant A. W. Müller, the Commander of the steamer running between Bergen and Iceland, has found this summer, by

several observations taken at different times, a temperature of about $+8^{\circ}$ Cent. [44° Fahr.] on the bottom, in a depth of 300 fathoms, between Iceland and the Faroe Islands. What a contrast to the distribution of temperature in the Channel between the Faroe Islands and Shetland!"—It is very interesting thus to find the deep Norwegian Fjords showing the same phenomenon of uniform temperature as other deep land-locked Seas. In my Report for 1869, I pointed out (§ 104) that the comparative shallowness of the bottom between Iceland and the Faroe Islands would interpose an effectual barrier to any glacial current moving southwards at a depth exceeding 300 fathoms.

The Hydrographer to the Admiralty has been good enough to furnish me with the following very interesting series of Temperatures recently taken in the Eastern Seas by Capt. Chimmo with the "protected" Thermometers.—As only a single Thermometer was used in each observation, it seems probable that the Temperatures marked (?) may be more or less incorrect.

Station...	A.	B.	C.	D.	E.	F.	
	$^{\circ}$ Fahr.	$^{\circ}$ Fahr.	$^{\circ}$ Fahr.	$^{\circ}$ Fahr.	$^{\circ}$ Fahr.	$^{\circ}$ Fahr.	
Surface ...	85.0	81.0	82.8	82.5	84.0	82.5	<i>Indian Ocean, between</i>
10 Fath.	83.2	.....	82.8	82.0	.....	81.5	<i>Ceylon and Sumatra.</i>
40	.....	.....	82.2	.....	.....	.....	Station A. Lat. $0^{\circ} 35' N.$, Long. $89^{\circ} 26' E.$
50	82.8	.....	.....	.....	71.5	.....	Station B. Lat. $3^{\circ} 24' N.$, Long. $84^{\circ} 44' E.$
70	.....	.....	68.8	.....	.....	65.0	Station C. Lat. $3^{\circ} 18' S.$, Long. $95^{\circ} 39' E.$
100	58.5	.....	.....	.....	62.0	.....	
150	.....	.....	54.2	.....	.....	.....	
200	.....	.....	.....	54.0	51.0	56.2	
250	.....	.....	50.5	.....	.....	.....	
300	.....	.....	.....	.....	46.0	.....	<i>Celebes Sea.</i>
350	.....	.....	.....	.....	42.5	.....	Station D. Lat. $4^{\circ} 14' N.$, Long. $123^{\circ} 9' E.$
400	.....	.....	.....	40.0	.....	.....	The comparatively high
450	.....	.....	.....	.....	41.5	.....	bottom Temperature of
550	.....	.....	.....	40.7(?)	37.0	.....	this Sea, notwithstanding
750	.....	.....	40.2	.....	37.5	.....	its great depth, is exactly
800	.....	.....	.....	39.0	.....	54.0	what might be expected
850	.....	.....	.....	.....	37.0	.....	from its <i>partially</i> land-
900	43.0	.....	.....	.....	37.0	.....	locked position.
1100	.....	.....	.....	.....	.....	50.0	
1300	.....	.....	36.9	43 (?)	.....	.....	<i>China Sea, near Paracel's</i>
1400	42.8	.....	.....	.....	.....	.....	<i>Islands.</i>
1778	.....	.....	.....	.....	.....	50.0	Station E. Lat. $17^{\circ} 50' N.$, Long. $111^{\circ} 24' E.$
1800	.....	.....	35.2	.....	.....	.....	
1900	33.0(?)	.....	.....	.....	.....	.....	
2270	.....	34.8	.....	.....	.....	.....	<i>Sulu Sea.</i>
2306	34.5	.....	33.6	.....	.....	.....	Station F. Lat. $8^{\circ} 5' N.$, Long. $119^{\circ} 43' E.$
2656	.....	.....	32.0	.....	.....	.....	
2667	.....	.....	.....	38.5	.....	.....	

APPENDIX.

I. ON THE GULF-STREAM, IN RELATION TO THE GENERAL
OCEANIC CIRCULATION.

85. The question how far the Climate of Northern Europe, and the temperature of the Arctic Sea between Iceland and Nova Zembla, is modified by the Gulf-stream, has of late been much discussed among Physical Geographers; and opinions the most contrary have been expressed on the subject. For whilst it is maintained by some that there is ample evidence of the amelioration of that Climate by a North-easterly *stream of Oceanic* water, bearing with it the warmth of a more Southern latitude, and further, that this flow is essentially a prolongation of the Florida Current or Gulf-stream proper, still bearing with it a large measure of the initial force which it derived from the Trade-winds, it is asserted by others that the Gulf-stream proper dies out in the Mid-Atlantic, shortly after encountering the Arctic Current off the Banks of Newfoundland; and that it consequently exerts no other influence on the Climate of Northern Europe and on the temperature of the Arctic Sea, than as contributing to the warmth of the South-westerly winds which blow from the area traversed by the Gulf-stream towards the British Islands and the Scandinavian Peninsula, and, by their prevalence over all others, maintain a North-easterly *surface-drift* over the portion of the North Atlantic which washes their shores.

86. Now since the doctrine of a General Oceanic Circulation dependent on difference of Temperature, which I have advocated in my successive Reports, will, if admitted, reconcile these opposing views,—by giving a *vera causa* for that *deep* flow of water from the warmer area of the North Atlantic towards the Polar Sea which Thermometric observations unmistakably indicate; whilst it accepts as of no less value the conclusions of those who, after a careful study of the Florida Current, are satisfied of its entire inadequacy to perform the function assigned to it,—I think it worth while to develop this doctrine somewhat more fully with special reference to the question of the Gulf-stream; more especially since my views have been strangely misunderstood by some of those who have taken prominent parts in the controversy.—In order to place this question fully before the Scientific public, I shall briefly summarize the opinions which have of late years found advocates among men whose knowledge of the subject entitles their views to respectful consideration.

87. The doctrine of the Gulf-stream prevalent thirty years ago was thus unhesitatingly expressed by Humboldt in the first volume of his ‘Kosmos’ (1844):—“It pours itself from the Caribbean Sea and the Mexican Gulf “through the channel of the Bahamas, and, following a direction from “S.S.W. to N.N.E., deviates more and more from the coast of the United

"States ; until, deflected still further to the east by the banks of Newfoundland, it crosses the Atlantic, and casts an abundance of Tropical seeds on the coasts of Ireland, of the Hebrides, and of Norway. Its north-easternmost prolongation mitigates the cold of the ocean, and exercises a beneficent influence on the climate of the northernmost point of Scandinavia. At the point where the stream is deflected to the east by the banks of Newfoundland, it sends off an arm toward the south, not far from the Azores." (Sabine's Translation, vol. i. p. 301.)

88. General Sabine appears to have been the first to suggest, in a valuable Note to the passage just cited (p. 454), that the transport of Tropical products, as well as of the warmer water of the Mid-Atlantic, to the North Cape, may be due to other agencies than the propulsive force of the Florida Current.—"It appears to require a further investigation to decide whether the Stream-current referred to in the text, which flows along the coast of Norway and round the North Cape of Europe, and is, at least, mainly supplied from the accumulated waters of the drift propelled by the West and South-west winds which prevail to the northward of the Trades, derives any portion whatsoever of its force from the original impulse given to the waters of the Gulf-stream at its outlet from the Gulf of Mexico, in the Bahama Channel. The transport of West-Indian seeds to the coast of Norway is undoubted ; and even parts of the cargoes of vessels wrecked on the coast of Africa have reached the Norwegian coast, after having made the circuit of the West-Indian Islands :—[such an instance occurred when the Editor was at Hammerfest, near the North Cape of Europe, in 1823 ; casks of palm-oil were thrown on shore, belonging to a vessel which had been wrecked at Cape Lopez, on the African coast, near the Equator, under circumstances which had made her loss a subject of discussion when the Editor was in that quarter of the globe, the year preceding his visit to Hammerfest]. But it is quite conceivable that objects conveyed a certain distance by the Gulf-stream, and thrown off on its north side into the waters which do not participate in its movement, may be subsequently drifted by the prevailing Westerly and South-westerly winds, in accompaniment with the surface-water of the sea, across the remaining portion of the Atlantic. The stream-current which terminates in ordinary years at the Azores, and which in rare instances extends to the coasts of Europe, is unquestionably traceable the whole way back to the outlet of the Gulf of Mexico, by a continuous strength of current and warmth of water ; but with respect to a northern branch of the Gulf-stream, supposed to detach itself to the N.E., and to convey the waters which have issued through the Bahama Channel in a continuous stream to the North Cape of Europe, *positive information is greatly wanting.*"

89. The elaborate investigations of Prof. Dove on the Temperature of the Earth, embodied in the Isothermal charts which he published in 1847-48, afforded strong confirmation of the doctrine that a N.E. movement of Atlantic water serves to carry a large amount of heat from the Temperate zone

within the Arctic area; and he inferred, from the direction of the Iso-thermal curves, that the influence of the Gulf-stream extends as far as Nova Zembla*.

90. The doctrine of the Gulf-stream as the efficient *heater* of North-western Europe, and of the Sea that stretches from it towards the Pole, found an enthusiastic and eloquent advocate in Capt. Maury. "There is," he says, "a river in the ocean: in the severest droughts it never fails, and in the mightiest floods it never overflows; its banks and its bottom are of cold water, while its current is of warm; it takes its rise in the Gulf of Mexico, and empties into Arctic Seas: this mighty river is the Gulf-stream,"—which, he affirms, discharges over the Atlantic in a winter's day a quantity of heat "sufficient to raise mountains of iron from zero to the melting-point, and to keep in flow from them a molten stream of metal greater in volume than the waters daily discharged through the Mississippi river;" or as "sufficient to raise the whole column of atmosphere that rests upon France and the British Islands from the freezing-point to summer-heat."—Capt. Maury, however, contests the doctrine originated by Dr. Franklin and supported by Rennel, as to the propulsive force by which the Gulf-stream is sustained: for instead of attributing it, like his predecessors, to the action of the Trade-winds in driving the Equatorial Current into the Gulf of Mexico, where, by the narrowness of its channel of exit it is converted from a superficial *drift*-current into a deep *stream*-current, he assigns it to a combination of other agencies, the operation of which, however, he rather indicates than distinctly specifies. Thus, he says, "modern investigations seem to encourage the opinion that this stream, as well as all the *constant* currents of the sea, is due *mainly* to the *constant* difference produced by Temperature and Saltness in the Specific Gravity of water in certain parts of the ocean. Such difference in specific gravity is inconsistent with aqueous equilibrium; and to maintain this equilibrium these great currents are set in motion. The agents which derange equilibrium in the waters of the sea, by altering specific gravity, reach from the Equator to the Poles; and in their operations they are as ceaseless as heat and cold; consequently they call for a system of perpetual currents to undo their perpetual work." Again,—“As for the seat of the forces which put and keep the Gulf-stream in motion, theorists may place them *exclusively* on one side of the Ocean with as much philosophical propriety as on the other. Its waters find their way into the North Sea and the Arctic Ocean in virtue of their specific gravity; while water thence, to take their place, is, by virtue of its specific gravity and by counter-currents, carried back into the Gulf. The dynamical force which causes the Gulf-stream may therefore be said to reside both in the polar and in the inter-tropical waters of the Atlantic.”

91. The whole of Capt. Maury's reasoning on this point, however, is

* "Ueber Linien gleicher Monatswärme," in Berlin Abhandl. (Phys.) 1848, p. 209; and British Association Report for 1848, p. 84.

directed to prove that the various causes which produced disturbance of equilibrium (among which he enumerates the abstraction of Carbonate of Lime from the Ocean-water by the Coral-forming polypes) are adequate to sustain *sensible currents*, such as the Gulf-stream. "A constantly acting "power," he says, "such as the force of gravitation, is as necessary to keep "fluids as it is to keep solids in motion. In either case the projectile force "is soon overcome by resistance; and unless it be renewed, the current in "the sea will cease to flow onward, as surely as a cannon-ball will stop its "flight through the air when its force is spent. . . . A propelling power, "having its seat only in the Gulf of Mexico, or the trade-wind region, "could no more drive a jet of water across the ocean, than any other single "impulse could send any other trajectory that distance through either air "or water. The power that conveys the waters of the Gulf-stream across "the ocean is acting upon them every moment, like gravity upon the "current of the Mississippi river; with this difference, however, the Mis- "sissippi runs down hill, the Gulf-stream on the dead level of the sea. "But if we appeal to salt and vapour, to heat and cold, and to the secreting "powers of the insects of the sea, we shall find just such sources of ever- "lasting changes and just such constantly acting forces as are required to "keep up and sustain, not only the Gulf-stream, but the endless round of "currents in the sea, which run from the equator to the poles, and from "the poles back to the equator; and these forces are derived from differ- "ence in specific gravity between the flowing and reflowing water. The "waters of the Gulf as they go from their fountain have their Specific "Gravity in a state of perpetual alteration in consequence of the change of "Saltness, and in consequence also of the change of Temperature. In these "changes, and not in the Trade-winds, resides the power which makes the "great currents of the sea." (Physical Geography of the Sea, Chapter II.)

92. The doctrine of Capt. Maury was powerfully and convincingly opposed by Sir John Herschel; who showed, beyond all reasonable doubt, *first*, that the Gulf-stream really has its origin in the propulsive force of the Trade-winds, and *secondly*, that the greatest disturbance of equilibrium which can be supposed to result from the agencies invoked by Capt. Maury would be utterly inadequate to generate and maintain either the Gulf-stream or any other sensible current (Physical Geography, §§ 51-60). But Sir John Herschel did *not* regard the initial force of the Gulf-stream as adequate to carry it across the Atlantic Ocean, still less to propel it as far as the Arctic Sea; for he speaks of it as *dispersed, and in fact destroyed*, by the process of thinning-off and superficial extension, about the 42nd or 43rd parallel of N. Latitude; and regards the N.E. flow of warm water towards the opening of the Arctic Sea between Spizbergen and Norway as mainly a drift-current swept on by the south-west Anti-trades of extra-tropical latitudes. The Polar current which comes down partly from Baffin's Bay along the Labrador coast, and partly from the east side of Greenland, meeting the Gulf-stream on the Banks of Newfoundland,

and thence passing southwards between the Gulf-stream and the Coast of the United States, is regarded by Sir John Herschel as the return-current of that portion of the N.E. Drift which passes onwards into the Arctic basin, completing what (borrowing a term from Anatomy) I would call the *longer circulation*. On the other hand, the southern deflection of a large portion of the Gulf-stream to the east of the Azores, and its re-entrance into the Equatorial current, complete the *shorter circulation*.

93. As Sir John Herschel, when placing himself in antagonism to the doctrine of Oceanic Circulation propounded by Capt. Maury, was himself an adherent of the doctrine of the uniform Deep-sea temperature of 39° , which had been propounded by Sir James Ross, on the basis of observations now proved to have been vitiated by the imperfection of his Thermometers, his repudiation of Capt. Maury's views must be understood as extending only to the question of *sensible currents*. As to the existence of any *more general*, though less perceptible, *surface-movement* of Oceanic water from the Temperate towards the Polar seas, Sir J. Herschel offered no opinion; nor did he at that time (so far as I am aware) anywhere express himself as either favouring or opposing the hypothesis of a movement of *deep* water from the Polar to the Equatorial areas, which would seem necessary for the maintenance of a bottom-temperature even of 39° in the latter, much more of a bottom-temperature but little above 32° .*

* As the doctrine advocated in my previous Reports, of a General Oceanic Circulation sustained by difference of Specific Gravity arising out of difference of Temperature, differs essentially from that of Capt. Maury,—in that it leaves unquestioned the Trade-wind origin of the Gulf-stream, and touches only that *deep* N.E. movement of Warm water which the Gulf-stream (on Sir J. Herschel's own showing) could not produce, and that *still deeper* return-movement of Cold water of which Sir J. Herschel was then ignorant,—I cannot but feel surprised at finding his authority cited against me, not only by Mr. Croll, but also (inferentially at least) by Sir Charles Lyell; who, in the recently published Eleventh Edition of his 'Principles of Geology,' speaks as follows (vol. i. p. 505):—"Besides those sensible currents arising from the various causes already mentioned, a theory of general oceanic circulation first propounded by "Maury has lately been brought into great prominence by Dr. Carpenter." Now, as I have shown, the "theory of general oceanic circulation propounded by Maury," had special reference to *sensible currents*; and it was the inadequacy of the causes assigned by him (not by me) for their production, which was the subject of Sir John Herschel's demonstration, cited by Sir C. Lyell in a subsequent page (p. 507). Yet by representing my views as identical with Capt. Maury's, Sir C. Lyell has (perhaps unintentionally) given the impression that Sir J. Herschel's demonstration was equally applicable to both. And he has been so understood by an anonymous writer in the 'Athenæum' (March 2, 1872); who, in a notice of Sir Charles Lyell's new edition, asserts, with reference to "the question of Ocean-Currents, which has been lately brought very prominently forward by Dr. Carpenter," that "Sir Charles shows that the theory which "refers oceanic circulation to difference of specific gravity is founded upon erroneous observation and incorrect application of the facts observed."—How differently Sir John Herschel thought of the doctrine as advocated by me (not in *substitution* for the Trade-wind origin of the Gulf-stream, but as *supplemental* to the whole Oceanic

94. The general acceptance of the doctrine of the uniform Deep-Sea Temperature of 39° , based on the observations of Sir James Ross, and sanctioned by the authority of Sir J. Herschel, caused the earlier doctrine of Humboldt and Pouillet (§ 18) to be lost sight of, until it was brought again into notice by the more trustworthy observations recently made with Thermometers 'protected' against the effects of pressure (§ 10).

95. The views of Sir John Herschel and others in regard to the non-extension of the Gulf-stream *as such* into the Polar area, were warmly contested twenty years ago by Dr. Petermann; who, in a letter addressed to Sir Francis Beaufort (then Hydrographer to the Admiralty *), explicitly asserted, on the basis of Temperature-observations, that the influence of the Gulf-stream extends from Newfoundland along the north coast of Europe and Asia, as far as Cape Jakan, in the vicinity of Behring's Strait. And this doctrine he has since urged in several successive Memoirs in the 'Geographische Mittheilungen;' with the addition that he now regards as a branch of the Gulf-stream a current of warm water which passes up the east side of Davis's Straits, and which is traceable as far as Smith's Sound.—But, as will presently appear (§ 106), Dr. Petermann uses the term "Gulf-stream" in a sense very different from that in which it is ordinarily employed in this country.

96. On the other hand, Mr. A. G. Findlay, in a Paper on the Gulf-stream presented to the Royal Geographical Society, Feb. 8, 1869, essayed to prove—on the basis of the data supplied by the operations of the United States Coast Survey as to the rate, volume, and temperature of the Gulf-stream in its passage through the Florida Channel, and by the changes in these three conditions which it undergoes during its course as far as the Banks of Newfoundland,—that after encountering the Arctic Current on the Banks of Newfoundland, the Gulf-stream loses all its original characters, and can no longer be distinguished from the general North-easterly drift of the North Atlantic; and that our mild climate, being in no way dependent on its influence, is to be accounted for as follows:—"The great "belt of Anti-trade or passage winds which surround the globe northward "of the Tropics, passing to the north-eastward, or from some point to the "southward of west, passes over the entire area of the North Atlantic, and "drifts the whole surface of that ocean towards the shores of Northern "Europe and into the Arctic basin, infusing into high latitudes the temperature and moisture of much lower parallels; and this alone would be "sufficient to account for all changes in climate by their variations, without any reference whatever to the Gulf-stream."

97. The views of Mr. Findlay as to the limited agency of the Gulf-

Current system kept up by the action of Winds on the surface), has already been shown (§ 37).

* "Further Correspondence and Proceedings connected with the Arctic Expedition," Parliamentary Blue Book, 1852, pp. 142 *et seq.*

stream proper have found much support in the United States, from men eminently qualified, by their knowledge of its Hydrographical phenomena, to estimate its real influence on the temperature of the North-east extension of the Atlantic. Thus Mr. G. W. Blunt, "the head of the well-known house that has for nearly a century prepared and published the charts that have guided the American Mariner in every quarter of the globe," says in a letter to the President of the American Geographical and Statistical Society,—“Beyond the Western Islands, I believe the Gulf-stream has no existence; and its alleged effects on the climate of the British Islands are matters of assertion only. The Gulf-stream, as a current, I believe, entirely ceases and loses all its equatorial heat to the eastward of W. Long. 40°; the set to the east is that of the general set of the North Atlantic, and the temperature of the water is that of the general temperature in those regions”*. And Dr. Hayes, the Arctic explorer, who formerly participated in the prevalent belief as to the extended agency of the Gulf-stream, has recently been so completely convinced by Mr. Blunt’s representations, that he has written an elaborate article on “The Real Gulf-stream”†, for the purpose of correcting the prevalent idea that the Gulf-stream influences the temperature of the North Atlantic. “It is an error,” he says, “into which many persons (including the writer of this article) have been led through lack of familiarity with facts, to suppose that the Gulf-stream sends off a branch from its northern limit to the Arctic Ocean, or even, as we shall presently have occasion to show, that it touches any part of the coasts of Europe.” “Being a resultant current, and having no force applied to it to keep it in motion, its strength diminishes; the air of a higher latitude brings its temperature down to that of the North Atlantic generally; the water loses all its Gulf-stream character, as to course, warmth, and flow; and it dies away into the sluggish Atlantic drift which sets from a westerly to an easterly direction.”—Dr. Hayes adopts the view of Mr. Findlay, that the amelioration of the climate of the British Isles and of regions further north is mainly due, as Dr. Stork had previously maintained (*Nautical Magazine*, 1857), to the prevalence of South-westerly winds; and he affirms, with Dr. Stork, that the temperature of the sea rather *follows* than *controls* that of the superincumbent air.

98. On the other hand, the doctrine of Dr. Petermann finds an enthusiastic advocate in Capt. Silas Bent‡; who not only maintains that the thermal influence of the Gulf-stream is traceable to Spitzbergen and Nova Zembla, but attributes to its agency the whole difference between the

* *Journal of the American Geographical and Statistical Society*, vol. ii. (1870) part 2, pp. cvi *et seq.*

† *Harper’s Atlantic Monthly*, Jan. 1872.

‡ Addresses on “The Thermometric Gateways to the Pole,” delivered before the Historical Society of St. Louis (U. S.), 1869, and before the St. Louis Mercantile Library Association, Jan. 6, 1872.

winter climate of Naples and that of New York,—even going so far as to affirm that the Gibraltar Current is a branch of the Gulf-stream carrying its heat into the Mediterranean, although Thermometric evidence shows that the Gibraltar Current rather *reduces*, than raises, the temperature of that inland sea.

99. The doctrine of the extension of the Gulf-stream proper to the Polar area, carrying with it a vast amount of Equatorial heat, has been advocated with great ability by Mr. James Croll; who, employing the modern method of computing *units of heat*, essays to prove that the quantity of heat carried from the Equatorial area by the Gulf-stream is so enormous, as to be competent not only to do all that Dr. Petermann attributes to it, but a great deal more*. In this, indeed, he goes far beyond Dr. Petermann himself; for, as will presently appear, Dr. Petermann regards the Florida Stream as furnishing only a part of the thermal power exerted by the vast body of water derived from various sources, to which he gives the name "Gulf-stream."

100. Without attempting to follow Mr. Croll through his calculations, I may stop to point out what appear to me to be the fallacies of his method; since if this can be proved erroneous, Mr. Croll's great array of figures is utterly valueless.

101. In the *first* place, in Mr. Croll's preliminary comparison of the Temperatures of the Northern and Southern Hemispheres, he altogether ignores the influence on the Distribution of Heat over the Globe which is exerted by the great relative preponderance of Land in the Northern Hemisphere. Yet of the vast importance of this influence, no Meteorologist or Physical Geographer can entertain the smallest doubt. The manner in which it affects the relative Temperatures of the North and South Atlantic will be hereafter shown (§ 118) to be precisely conformable to that in which it manifests itself in the Climates of Continental Stations; and to affirm, as Mr. Croll does, that "the lower mean Temperature of the Southern Hemisphere is due to the amount of heat transferred over from that Hemisphere to the Northern by Ocean-Currents," is to repudiate all that has been established by the researches of Meteorologists, as to the relative effects of Land and Sea, not only upon Temperature, but upon Atmospheric Vapour, Barometric Pressure, and the prevalent Direction of winds,—in all of which particulars the contrast between the Northern and Southern Hemispheres is so marked, that any transfer of Heat from the latter to the former which can be fairly attributed to Ocean-currents, must be comparatively insignificant in its effects.

102. Secondly, in computing the Heat imparted by the Sun to the Equatorial area from which the Gulf-stream is fed, Mr. Croll assumes

* See his Papers "On Ocean-currents," parts I. and III., in *Philosophical Magazine*, Feb. and Oct. 1870; and "On the Influence of the Gulf-stream," in *Geological Magazine*, April 1869.

that this heat, being wholly taken up by the Water of the Ocean, is transferred by its currents towards the Polar regions; whilst of the heat which falls upon the Land, a very large proportion is lost by radiation, passing off into the stellar spaces. "It is in the Equatorial regions," he says, "that the *earth* loses as well as gains the greater part of its heat; so "that, of all places, here ought to be placed the substance best adapted "for preventing the dissipation of the earth's heat into space, in order "to raise the general temperature of the earth. *Water*, of all substances "in nature, seems to possess this quality to the greatest extent; and, besides, "it is a fluid, and therefore adapted by means of currents to carry the heat "which it receives from the sun to every region of the globe"* . Now in this assumption two facts are entirely ignored:—*first*, the very small depth to which the superheating influence of direct insolation penetrates, as is shown in the temperature-soundings taken during my two Mediterranean cruises (see § 67); and *second*, the conversion of a vast amount of the solar heat which falls upon the Ocean into the elastic force of vapour, its surface-temperature being *kept down* to a tolerably regular maximum by evaporation, just as the surface-temperature of the Human body is kept down to a uniform maximum by its insensible perspiration. The *maximum* surface-temperature ever observed in the open Ocean is never (so far as I have been able to ascertain) above 86°, the ordinary maximum being about 82°; and any higher temperature seems only to show itself in the near neighbourhood of land,—as along the Guinea Coast, and in the Red Sea, where a temperature of 90° is said to have been noted. Yet the direct heat of radiation, measured by a thermometer with a blackened bulb, laid upon a black surface, has been seen at Aden (as I am informed by Col. Playfair) to raise the mercury to 215°. The enormous amount of heat thus converted into the elastic force of vapour must be carried into the upper regions of the atmosphere; and whether that vapour be there condensed into the heavy rain which falls in the region of equatorial calms, or be transported by atmospheric currents to some remote region, there to undergo condensation, the heat thus lost by *evaporation* from the *sea* must be far greater than that lost by *radiation* from the *land*.

103. In the third place, Mr. Croll leaves almost entirely out of the question the N.E. transportation of an enormous amount of heat from the *general surface of the Atlantic* by the agency of the *Aqueous Vapour* thus raised; although the importance of this agency has been insisted on by the most eminent authorities in Meteorology. "Thus," says Sir John Herschel (Meteorology), "aqueous vapour becomes an agent in the transfer "of heat, in its latent state, from one part of the globe or from one region "of the atmosphere to another." And Sir Charles Lyell, after citing this passage, continues:—"The upper trade-winds (or Anti-trades), which

* "On Ocean-currents in relation to the Distribution of Heat over the Globe," in *Philosophical Magazine*, Feb. 1870, p. 86.

"pass freely above the peaks of all but the highest mountains, are able to pursue an almost unbroken course over tropical and subtropical latitudes, until they come to those more northern regions where the act of condensation releases probably three-fourths of their heat"*.—But, says Mr. Croll, "the heat of our south-west winds is derived, not directly from the Equator, but from the warm water of the Atlantic—in fact from the Gulf-stream The greater part of the moisture of the south-west and west winds is derived from the ocean in temperate regions . . . The greater part of the moisture received at the Equator is condensed and falls as rain in those regions." Now to any one who examines the proportion borne by the area of the true Gulf-stream, before its easterly bend, to that of the great Sargasso sea of the Mid-Atlantic, which has a temperature only a few degrees lower than that of the Florida Current in corresponding latitudes, and in no way dependent upon it, the assertion that the warmth and moisture of our S.W. winds is essentially dependent on the Gulf-stream, is obviously untenable. So, also, is the statement that moisture cannot be thus conveyed from Intertropical to Temperate regions, because the heated air charged with it *must* ascend at once into regions so cold that all its moisture will be condensed: for if this were the case, the enormous mass of water raised by evaporation from the surface of the Red Sea (calculated by Dr. Buist as equal to *eight feet* of depth per annum) ought to fall back again into the Red Sea or the area immediately surrounding it; and yet, as is well known, the greater part of that area is almost entirely *rainless*.

104. Fourthly, until corrected by Mr. Findlay, Mr. Croll assumed that the whole of the true Gulf-stream continues to flow in a N.E. direction; whereas it is unquestionable that a considerable proportion of it (probably more than one half) turns southward to the east of the Azores, and re-enters the Equatorial current. This portion, however, Mr. Croll regards as the principal *heater* of the S.W. winds which impart warmth to the British Islands; whilst the portion of the current which he assumes to flow past our Islands up into the Arctic seas, he regards as the *heater* of the S.W. winds which go to warm Norway and the North of Europe.—Now the fact is, as I shall show hereafter (§ 147), that the large division of the Gulf-stream which thus turns *southwards* possesses no excess of temperature above the general mass of Atlantic water in that region, being only recognizable by its movement. And as to the portion which passes *northwards*, we shall see that its Area is so small in relation to the general surface of the Atlantic through which it passes, and that its Temperature is so little in excess of that of the water on either side of it, as to render its Thermal effect very insignificant (§§ 150, 157).

105. The difference between Mr. Croll's representation of the amount of Heat actually carried out by the Gulf-stream, and the actual facts of

* 'Principles of Geology,' Eleventh Edition, vol. i. p. 238.

the case, will be more fittingly pointed out hereafter (§§ 139-142). At present I venture to think that I have made it evident that the real influence of the Gulf-stream upon the Thermal condition of the North Atlantic must be determined in some other way than by a theoretical computation of "units of heat," for which no truly reliable data can be said to exist. It is from *the position and course of the Isothermal Lines*, which have now been laid down over its whole area for different seasons on the basis of a large number of observations, that we derive our surest information as to the actual effect produced on the surface-temperature of the Mid-Atlantic by the transfer of water in the Gulf-stream from the Intertropical to the Temperate zone, and as to the course and amount of the further movement whereby the water of the Temperate zone is carried towards the Polar area.—This is the method of investigation which has been followed by Dr. Petermann in his recent very important Memoir on "The Gulf-stream, and our knowledge of the Thermal condition of the North Atlantic Ocean and its Continental Borders, up to 1870" *; and it will be found that however much I may seem to differ from him in refusing to the "Gulf-stream" any important share in the amelioration of the Climate of the British Islands, and of the regions lying to the north of them, the difference is more verbal than real.

106. Dr. Petermann's view will be best expressed in his own words:—

"My own ideas, in 1865, of the extent and of the immense volume of the Gulf-stream, I expressed as follows (Mittheilungen, pp. 150 *et seq.*):—'Instead of a weak and insignificant drift from Newfoundland toward Europe, as heretofore represented, I consider the northern part of the Gulf-stream one of the mightiest currents in the world, although comparatively but slow, not very perceptible on the surface of the ocean, and therefore of no great moment to navigation. I do so, because Ocean-Currents have to perform yet other functions than those of a strong surface-stream. In that view I conceive the Gulf-stream to be a *deep permanently warm current* from Newfoundland to the coasts of France, Great Britain, Scandinavia, and Iceland, up to Bear Island, Jan Mayen, and Spitzbergen; and along the western coast of the latter up to the 80th degree of N. Lat., thence to Nova Zembla into the Polar Sea, passing the northernmost capes of Siberia and the New Siberian Islands, where it appears on the charts as the Polynja of the Russians, discovered by Hedenström sixty years ago, and fully corroborated by Wrangell and Anjou, its influence being felt perceptibly

* 'Geographische Mittheilungen,' 1870, pp. 201-272.—A translation of this Memoir, with supplemental Notes, and other subsequent Papers in the 'Mittheilungen,' has been issued by the Hydrographic Office of the United States; and of this translation I have freely availed myself,—referring, however, to the original wherever I had reason to suspect that the meaning was inaccurately or imperfectly expressed.

“ ‘ even as far east as Cape Jakan in the vicinity of Behring’s Strait.’—
 “ In two Monographs since published (‘ The Northernmost Land of the
 “ Globe,’ and ‘ The Expeditions to the Arctic Ocean north of Behring
 “ Strait, 1648 to 1867 ’), I have traced a branch of the Gulf-stream up
 “ to Smith’s Sound, and another warm current from the Pacific Ocean
 “ through Behring’s Strait up to the Polar Land discovered by Kellett
 “ and Long.—Although, since 1865, high authorities have pronounced
 “ against my theory of the extent and volume of the Gulf-stream, I
 “ cannot but still maintain the same; and shall now produce the figures
 “ of the actual observations on which it is based, and without which we
 “ but drift into arbitrary suppositions.”

107. With reference to the objections advanced by Mr. Findlay, and by those who maintain the same opinion with him as to the limited agency of the *real* Gulf-stream, Dr. Petermann says :—“ That the Gulf-stream, “ in its course towards Europe, receives and unites with a drift corresponding in direction, is probable and natural; but it is equally certain that the former is the main body or principal stream of the North “ Atlantic waters at all times of the year. Of continental rivers the expression is used that they have their source or head and their mouth; “ but this does not imply that all the water emptying at the mouth comes “ exclusively from the small source. The Florida Stream may be compared with the head of a great river, which is swelled, in its course to “ the mouth, by tributaries. In the same manner, then, as a great river-basin is named from the principal river, it appears proper and to the “ purpose to retain for the warm North Atlantic current the name ‘ Gulf-stream.’ It surely would be difficult to ascertain where the Florida “ Stream ceases really; where it receives tributaries, and how many; and “ what part of the temperature of the combined stream is ascribable to the “ Florida Stream, and what to the tributaries. The name ‘ Gulf-stream ’ “ has been adopted so generally for the great Oceanic current which bathes “ the European shores, that it would be better to call the head and the “ first part of the course ‘ Florida Stream,’ than to use for the other “ part a new and complicated name, instead of one long known and now in “ general use.”—This view has lately received the sanction of Sir Charles Lyell :—“ It has been objected that we have no right to attribute to the influence of the Gulf-stream the warmth of all the water which we may find “ in the Northern Atlantic above the normal temperature of the latitude. “ But when recognizing the influence of that stream in the Atlantic, we do “ not, as Dr. Petermann justly observes, refer the whole of it to the Current “ which flows out of the Gulf of Mexico, or deny that it has received “ accessions upon its way: we rather retain the name of Gulf-stream just “ as we do that of a river from its source to its delta, although many tributaries coming from different regions may have swollen and modified “ its volume” *.

* ‘ Principles of Geology,’ Eleventh Edition, vol. i. p. 504.

108. I cannot but regret that an analogy so fallacious should have been put forth by a Physical Geographer of Dr. Petermann's reputation, and should have been adopted by the distinguished author of the 'Principles of Geology.' A River-current (provided it has an adequate fall) continually *increases* in strength and volume by the accession of water brought into it by its tributaries; and the retention of the same name from its principal source to its mouth is therefore perfectly appropriate. But an Oceanic Stream-current, maintained by its initial force alone, tends gradually to *diminish* in strength, through the retardation it is constantly undergoing by friction, until at last it merges in the general body of water through which it flows. And if that water has a movement of its own, quite independent of any slight residual propulsive force which it may receive from the current discharged into it, nothing but confusion can arise from assigning to it a name which implies that it is as much the continuation of that Stream, as a river at its mouth is of a river at its source.—Of the misapprehension liable to arise from such an inappropriate use of names, I shall now give a notable instance.

109. Dr. Petermann, after quoting from my Lecture (delivered at the Royal Institution, February 11, 1870), on the results of the first 'Porcupine' Expedition, a passage in which I express a doubt whether the influence of the "Gulf-stream proper" reaches the European shores of the Atlantic, and citing Mr. Jeffreys as to the evidence afforded by the Arctic character of the Mollusca of this part of the Ocean in disproof of the extension of the Gulf-stream to the coasts of Ireland and Scotland, continues as follows:—"The upper warm stratum of the North Atlantic Ocean, between 'Ireland and the Faroes, was computed, from the soundings of the " 'Lightning' and the 'Porcupine' Expeditions, to have a depth of not " less than 700 to 800 fathoms, which, of course, excludes the idea of a " drift or surface-current, and most strongly fortifies the theory of a *deep, " voluminous, warm stream*. Therefore Carpenter and Jeffreys, while " denying the extension of the Gulf-stream into those latitudes, *produce " the strongest evidence against their own assumption*." Now it would scarcely be supposed from this reference to my views, that in the sentences immediately preceding and following the one cited by Dr. Petermann, I most distinctly recognized the existence of this "deep, voluminous, warm stream" moving from the South-west towards the North-east; making its very depth and volume the basis of my argument that it "*cannot be a " continuation of the Florida Gulf-stream*, but that it must form part of a "*great general movement of Equatorial water towards the Polar area*," the complement of "*the great general movement of Polar water towards the " Equatorial area*, which depresses the temperature of the deepest parts of " the great Oceanic basins nearly to the freezing-point."

110. Again, in a previous part of the same lecture, I had spoken of this doctrine of a *great general Oceanic Circulation* sustained by difference of Temperature alone, as one of which Physical Geographers could not recog-

nize the importance, so long as they "remained under the dominant idea "that the Temperature of the Deep Sea is everywhere 39° ." Now, since in my previous Report of the 'Lightning' Expedition for 1868, I had specially drawn attention to the prevalent error of regarding the temperature of 39° as that of the Deep Sea generally (showing that it is *not* that of the greatest density of Sea-water, which contracts until it freezes), and had demonstrated the non-existence of the supposed line of equal temperature at all depths, separating the Polar sea, in which the temperature *rises* with increase of depth, from the Equatorial, in which it *sinks*, I cannot but feel greatly surprised at finding these errors repeated by Dr. Petermann, as well as by his coadjutors Drs. Von Preeden and Mühry, and determining their interpretation of many of the phenomena which they bring under discussion. Thus Dr. Petermann says of the Gulf-stream that "after coming forth intact from its two struggles with the Polar Stream "east of Newfoundland and east of Iceland, its waters cool more and "more towards the north, until they are reduced to a temperature of $39^{\circ}2$, "at which they attain their highest density and greatest weight. At this "temperature it sinks beneath the Polar Stream, in July, north of Iceland "and Spitzbergen, and on both sides of Bear Island . . . North of the isothermal curve of $39^{\circ}2$ toward the Pole, the temperature generally increases with the depth, while southward towards the Equator it decreases."—And Dr. Von Preeden says,—“It has been established beyond doubt, by “late investigations on the high seas, that *Sea-water* reaches its maximum “density, or in other words its greatest Specific Gravity, in exactly the “same manner as *fresh* water at a temperature of 3° R.” Dr. Mühry, also, though espousing the doctrine of a *vertical* circulation between Polar and Equatorial waters, maintained by difference of Temperature, altogether misconceives, under the influence of the error just stated, the effects of this circulation. “The vertical distribution,” he says, “is regulated by the “hydrothermal law, according to which *sea-water*, like *fresh* water, attains “its maximum density and gravity at about $39^{\circ}2$ Fahr. Of two streams “meeting each other, one or the other, the colder or the warmer, will soon “prove relatively less heavy; and this will continue its course on the “surface, while the heavier will submerge, and flow underneath the lighter, “provided that they cannot proceed side by side. *It must and can be “assumed* that there is at the bottom of the Polar basin really a temperature of $39^{\circ}2$ or nearly so; and that there is a gradual decrease of it to “the surface, where it is 28° , the lowest temperature of flowing water, “just near the point of congelation, below the floating field ice of about “eight feet in thickness, which, at the top, has perhaps a temperature of “ -58° (-40° R.).”—“This,” continues Dr. Mühry in a Note, “will be “disputed by Physicists, who cling to a few contradictory experiments; “Nature, however, offers more correct and decisive data, which are confirmed indisputably by the result of our inquiries into the vertical distribution of the Oceanic currents.” And the doctrine of the uniform Deep-

Sea temperature of $39^{\circ}2$, originally propounded by Sir James Ross, and unfortunately adopted (to be afterwards entirely abandoned) by Sir John Herschel, is then formally propounded by Dr. Mühry, as if it had not been completely exploded by the results of the 'Porcupine' and other recent Temperature-soundings.

111. Now the increase of density of Sea-water down to its freezing-point, which may be as low as $25^{\circ}4$, is as well established as any fact in Physics; while there is no *reliable* observation (made with Thermometers protected from the influence of pressure) which indicates a Deep-sea temperature of $39^{\circ}2$ in either the Arctic or the Antarctic basin.

112. It will be unnecessary for me to dwell at any greater length on my points of difference with Dr. Petermann; since it will be obvious to any careful reader of his Memoir, that its main object is to prove the existence of the North-easterly movement of a deep voluminous body of warm water (as distinguished from a surface-drift) in the North Atlantic; *on which point I entirely agree with him*. And although he applies to this flow what I cannot but consider the very inappropriate designation of the "Gulf-stream," he expressly guards himself from assigning to the initial force of the Florida Current (or Gulf-stream proper) the whole, or even a principal part, of the power by which this movement is sustained.

113. But a doctrine of the Gulf-stream has been put forth by my friend and colleague Prof. Wyville Thomson, to which I regret to find myself in direct opposition: for he regards the North-easterly movement of Dr. Petermann's "deep, voluminous, warm stream" as essentially due to the initial force of the Florida Current; and attributes its ameliorating effect on the temperature of the North Atlantic and Arctic seas to the heat which the Gulf-stream proper has brought from the Intertropical zone. "The basin of the North Atlantic," he says, "forms a kind of *cul de sac*;" "and while a large portion of the Gulf-stream water, finding no free outlet "towards the north-east, turns southwards at the Azores, the remainder, instead of thinning-off, has rather a tendency to accumulate in the northern portions of the trough. We accordingly find that it has a depth, on the west coast of Ireland, of at least 800 fathoms, with an unknown lateral extension." Further, he says, in "the shallow, including the Hebrides, the Orkney and Shetland Islands, and the Faroes, stretching westwards and northwards nearly to Scotland, the average depth is about 500 fathoms; "and the Gulf-stream, which has a depth in these latitudes in summer of "from 600 to 700 fathoms, occupies the whole of it, giving an abnormal temperature of something like 12°C. "*

114. The foregoing sketch of the recent history of this inquiry presents for our consideration four principal Doctrines respecting the causes of the abnormally high Temperature of the British Islands, and of the ameliora-

* See his Lecture "On Deep-Sea Climates," in 'Nature,' July 28th, 1870, and his "Address to the Scottish Meteorological Association," in 'Nature,' July 27th, 1871.

tion of the Climate of the region still further north, extending from Iceland to the east of Spitzbergen :—

i. That of Mr. Findlay, Mr. Blunt, and Dr. Hayes, who regard this elevation of Temperature as having no immediate relation to the Florida Gulf-stream, and attribute it mainly, if not entirely, to the prevalent influence of South-westerly winds and of the surface-drift they maintain ; the surface-temperature of the Sea being in their view entirely dependent on that of the Atmosphere above it.

ii. That of Dr. Petermann, who attributes it in great part to the north-easterly flow of a “ deep, voluminous, warm stream,” which he designates as the “ Gulf-stream,” while admitting that a large part, both of its movement and its temperature, may be due to the “ tributaries ” which the Florida current receives in its course. He does not, however, specially indicate any of these tributaries ; nor does he attribute the movement of his “ deep, voluminous, warm stream ” to any other agency than the residual force of the Florida current, aided by surface-drift.

iii. That of Prof. Wyville Thomson, who explicitly refers the North-easterly flow of Dr. Petermann’s “ deep, voluminous, warm stream ” to the propulsive force of the Trade-winds acting as a *vis à tergo* through the Florida current, and attributes the Thermal influence of that stream almost exclusively to the heat which the Florida Current transports into high latitudes from the Gulf of Mexico ; while he regards the underflow of Cold water into the Equatorial Ocean as an *indraught* to replace the Warm water carried off from its surface by the Equatorial current and Gulf-stream.

iv. My own view, which is partly coincident with the first, and partly with the second of those just enunciated. In common with Mr. Findlay, Mr. Blunt, and Dr. Hayes, I regard the progressively diminishing influence of the Florida Gulf-stream as scarcely traceable, either by movement or temperature, to the European border of the Atlantic ; whilst, in common with Dr. Petermann, I maintain (as I have maintained from the first) that a “ deep, voluminous, warm stream ” of Oceanic water, not to be accounted for by surface-drift, is continually flowing in a North-easterly direction between the parallels of 50° and 60° , the extension of which into still higher parallels is the main source of the amelioration of their climate. But I differ from him and from Prof. Wyville Thomson in maintaining that the northward movement of this deep voluminous stream is produced, not by a *vis à tergo*, but by an *indraught* of the Warm upper stratum of the Mid-Atlantic towards the Polar area, to replace the *outflow* of the Cold under-stratum which is constantly taking place over the Deep-sea bed, in virtue of the increase of Density which the Polar column acquires by the reduction of its Temperature. And I also maintain that the amelioration of the Temperature of the Northern area is only due to the Florida Current, in so far as it raises the temperature of the portion of the North Atlantic that lies between the parallels of 40° and 50° (it being from this portion that the

“deep, voluminous, warm stream” is derived), and imparts additional warmth (either in the form of sensible Caloric, or as the Latent Heat of watery vapour) to the South-westerly winds which move over its surface.

115. Now, as I have already remarked elsewhere*, although “to the *mere* Physical Geographer it may perhaps seem of little importance which “of these views is the correct one,”—the transfer of a vast amount of heat from the Equator towards the Poles by a continual movement of a great body of water being admitted on both sides,—“the question is one of the “highest *scientific* interest, from its relation to the general theory of Ocean “Currents, past as well as present. For if the doctrine of a General Oceanic “Circulation depending only on differences of Temperature be correct, it “comes in as an important element in the study of all other great Currents “at the present time, and especially of those of the Southern Oceans, which “seem much less attributable than those of the Northern to the *primum* “*mobile* of the Trade-winds. Further, the question is of yet greater im- “portance in its Geological relations; since any Circulation that has its “origin simply in difference of Temperature must have been maintained “throughout all geological epochs; and the formation of Glacial beds, “marked by the presence of the marine types of Polar waters, may have “been taking place at any time and in any part of the Equatorial Ocean, “without any reduction of the land temperature. Whereas if these glacial “currents are dependent for their origin on the motion communicated to “the true Gulf-stream (as Prof. Wyville Thomson maintains), they would “cease to flow over the deep bed of the Atlantic, if that stream were di- “verted by the free passage of the Equatorial current into the Pacific.”

116. I propose, then, to consider :—

I. The general Distribution of Heat in the Atlantic Ocean; especially with reference to the differences between the North and the South Atlantic.

II. The Thermal condition of the Gulf-stream, and its influence on that of the North Atlantic.

III. The evidence of amelioration in the Climate of the British Isles and of the regions still further north, by a North-easterly flow of Oceanic water.

IV. The question whether this flow is attributable to the initial force of the Gulf-stream proper, supplemented by the general North-easterly surface-drift of the Atlantic; or whether it is a larger and deeper movement, forming part of a General Oceanic Circulation sustained by difference of Temperature.

117. *General Distribution of Heat in the Atlantic Ocean.*—A comparison of the positions of the Summer and Winter Isotherms† in the North

* Proceedings of the Royal Geographical Society, Jan. 9, 1871, p. 70.

† I adopt as my authority for the Isothermal lines of the South Atlantic, and of the North Atlantic as far as 50° N. Lat., the ‘Current and Temperature Chart,’ issued by the Hydrographic Department in 1868, and the Monthly Temperature Charts of the North and South Atlantic, recently issued by the Meteorological Department; while

and the South Atlantic respectively (see Plate VII.) serves to show (as was well pointed out in the 'Onderzoekingen met den Zee-thermometer' published in 1861 by the Royal Meteorological Institute of the Netherlands) that, while *the North Atlantic is as a whole warmer than the South*, its Temperature *has also a much wider Annual range*: for the corresponding Isotherms lie at a greater distance from the Equator on its Northern than they do on its Southern side; and the central line of the belt of warmest water does not coincide with the Equator, but lies for the most part on its Northern side; so that the Thermic Equator, or line of *maximum mean* Temperature, falls some degrees to the north of the Geographical Equator. The line which divides the two Hemispheres climatologically of course shifts its position according to the seasons; but all these changes of situation take place to the north of the Equator, except in February and March, when this line has its most southerly position, and crosses the Equator in a few places. Again, comparing points at which the Isotherms cross the Meridian of 30° W. Long. in the *North Atlantic*, with the points at which they cross the Meridian of 20° W. Long. in the *South Atlantic*,—these two meridians being, as it were, the axes of their respective basins,—we observe that in the North Atlantic the distance between the Summer and the Winter Isotherms of 60° is nearly 15° of Latitude, whilst in the South Atlantic the distance between those two Isotherms is only about 7½°; and that a like difference shows itself between the seasonal positions of the Isotherms of 55° and 65° in the Northern and Southern Oceans respectively. The great regularity of the directions and distances of the Isotherms beyond the parallel of 30° S. Lat. in the South Atlantic, also, is very striking when contrasted with the irregularity, both in course and distance, which marks those of the North Atlantic. The Annual Range is observed to diminish in the South Atlantic as we pass from lower to higher latitudes; so that to the southward of the parallel of 42° S. the summer and the winter climates differ comparatively little from one another, whilst near the south point of South America the climate is remarkable for its mildness in winter.

118. Now these general differences between the Thermal conditions of the Northern and the Southern Atlantic are fairly attributable to that great *preponderance in the proportion of Land to Sea in the Northern Hemisphere*, which is fully recognized by all Physical Geographers and Meteorologists as an adequate *vera causa* alike for the higher *average* Temperature of the Northern Hemisphere as a whole and for its greater *annual range**. This preponderance is particularly marked in the Eastern Hemisphere, where, in the 180 degrees of Longitude which include the whole of Europe and very nearly the whole of Asia, the Thermic Equator is almost a great circle inclined at an angle of 15° to the Geogra-

for those of Latitudes beyond 50° North, I rely on the two Charts accompanying Dr. Petermann's Memoir.

* See Sir John Herschel's 'Physical Geography,' §§ 250-264.

phical Equator, crossing East Africa, Arabia, and the Peninsula of India nearly in that latitude north. According to Prof. Dove, the mean Summer temperature in the Northern Hemisphere is $70^{\circ}9$, while in the Southern it is $59^{\circ}5$; but, on the other hand, the mean Winter temperature of the Northern Hemisphere is $48^{\circ}9$, while that of the Southern is $53^{\circ}6$. Thus the *mean* between the Summer and Winter temperatures is $59^{\circ}9$ for the Northern Hemisphere, and $56^{\circ}5$ for the Southern; giving an excess of about $3\frac{1}{2}^{\circ}$ to the Northern. But the average *range* between the mean Summer and Winter temperatures for the whole Northern Hemisphere is 22° , while for the Southern it is only $5^{\circ}9$. The *highest* observed Annual Range in the whole Southern Hemisphere is only 40° , and this over a small area in Patagonia which does not cover a *hundredth* part of its surface; whilst this range amounts to 40° over about a *third* part of the surface of the Northern Hemisphere, and rises in the great Continental areas of Asia and North America even to 80° ; whilst a considerable area of Northern Asia has a range of 90° , rising in some places to 100° , and at Yakutsk (which lies in the centre of it) to 106° .*

119. It may be fairly assumed, therefore, that the general difference between the Thermal condition of the Northern and that of the Southern Atlantic Ocean,—as regards (1) the excess of Mean temperature, and (2) the greater Annual Range,—is essentially dependent on the same agency as that which produces those *much larger* general differences in the Continental Climates of the two Hemispheres, which cannot be attributed, with the least semblance of probability, to a transfer of Heat from the Southern to the Northern by Ocean-currents. For these last differences show themselves most remarkably in the Eastern Hemisphere, in which it is physically impossible that any such northward transfer of superheated surface-water can take place to any but a most limited extent; while there is strong evidence, from the low bottom-temperatures found even in the Arabian Gulf, that Polar Cold is imported to the North of the Equator all the way from the Antarctic Ocean †.

120. On more particularly comparing the course of the Isothermal lines in the North and in the South Atlantic (Plate VII.), we observe that in the *eastern* portion of the Oceanic basin, beneath the parallels of 40° North and 30° South, they tend *towards* the Equator. This is obviously due to the fact that, commencing from the coast of Portugal, a surface-flow proceeds *southwards* along the coast of Northern Africa as far as the Gulf of Guinea, carrying into the Intertropical area the colder water of the Temperature Zone; whilst there is a corresponding surface-flow of yet colder water *northwards*, from the Cape of Good Hope, along the coast of South Africa, as far as the Bight of Biafra. These currents are the main *feeders* of the Equatorial current; and although they may be partly sustained by the agency of prevalent Winds, I am disposed to believe that they are essentially

* See 'Handbook of Physical Geography,' by Keith Johnston, Jun., p. 180.

† See my Report for 1868, p. 187, note; and Report for 1869, p. 473, note.

indraughts maintained by a *vis à fronte* rather than by a *vis à tergo*. For it is obvious that the Trade-winds cannot be continually driving westwards the surface-water of the Intertropical region, unless that water is as continually re-supplied; and it is very curious to observe that while the portions of the North- and South-African currents which lie furthest from the coast are drawn into the general westerly drift that prevails over the Intertropical area, the part of each that lies nearest the coast follows its curvature, so that the two meet in the Bight of Biafra, which may be considered the "head water" of the great *Equatorial* current. The *eastward* deflection of a large part of the North-African current, along the whole line of the Guinea Coast, from Cape Verde and Sierra Leone to Fernando Po, only a little to the north of the *west*-flowing Equatorial current (the boundary between the two being almost as sharply defined as the "cold-wall" which separates the Gulf-stream from the Arctic current), is a fact of peculiar significance. And this significance becomes still more marked, as we find that this *Guinea* current is fed, not merely by the North-African current, but by an Easterly flow that is traceable across the Atlantic, usually between 6° and 8° N. Lat., on an average as far as 35° West, and sometimes almost to the coast of Guiana. This flow intervenes between the well-defined Equatorial current which is driven on by the S.E. Trade, and the more expanded Westerly Drift impelled by the N.E. Trade, of which the southern border has nearly the same rate as the Equatorial Current; and the area over which it takes place appears to correspond pretty closely with that of the "Equatorial Calms,"—the Thermic Equator, as already stated, lying a few degrees to the north of the Geographical Equator. Within this area the winds are variable; and neither here nor along the Guinea Coast does it seem that the easterly flow can be sustained by any prevalent movement of the Air in that direction. I would suggest, therefore, that the "Guinea Current" is mainly an *indraught* or supply-current, contributing, with the South-African current, to keep up the level of the head-water of the Equatorial current in the Bight of Biafra; and that, in like manner, the Guinea current itself draws upon (1) the North-African current, and (2) the "still" region of the Atlantic.

121. But besides the *indraught* propagated backwards (so to speak) from the Guinea Current, the still water that lies between the two great westerly Drift-currents will be likely to take on an Easterly movement of the kind known as *back-water**; for as the part of it in proximity to the current on either side is carried along by the friction of that current, a void will be created, which must be supplied by a flow of water in the opposite direction. And that this is partly the explanation of the more or less constant easterly movement of the band of Atlantic water which lies immediately to the North of the Equatorial Current, from the Guiana coast to the Bight of

* The phenomenon of "back-water" has been well explained and illustrated by Mr. Laughton in his 'Physical Geography in its Relation to the prevailing Winds and Currents.'

Biafra, appears from the fact that (as was first pointed out by Mr. Findlay*) there is a similar counter-current in the Pacific between the Northern and the Southern Equatorial, and that an analogous current is traceable also in the Indian Ocean, setting towards the coast of Sumatra.

122. With all this evidence of *surface*-indraught, therefore, we need have no difficulty in accounting for the constant supply of the "head-water" of the Equatorial Current, without having recourse to the hypothesis of a *bottom*-indraught of Polar water, which is resorted to by Prof. Wyville Thomson (§ 114, III.) to explain the prevalence of a glacial temperature over the Deep-sea bed. It seems obvious, on the axiomatic principle of "least action," that a *surface*-outflow will always be replaced by a *surface*-indraught, wherever this can be supplied; since a *bottom*-indraught would involve the lifting-up of the whole intervening stratum of water: and I am assured by Mathematicians and Physicists of the highest eminence, that this view is not open to question.—We shall hereafter see that the Westerly Drift which answers to the Equatorial Current in the North Atlantic, in its turn draws upon the terminal expansion of the Gulf-stream proper (§ 147).

123. Passing, now, to the *western* side of the North and South Atlantic, we observe that in both alike the Isothermal lines bend *away from* the Equator, in conformity with the known course of the two great divisions of the *Equatorial* Current. For as this sweeps across from the African to the American side of the Atlantic, and strikes full upon Cape St. Roque, which forms the salient angle of the South American Continent about 5° south of the Equator, it is (as it were) split in two thereby; and while the larger or northern division is slanted in a N.W. direction towards the Caribbean Sea, the smaller or southern division is forced to take a decided bend to the southward along the coast of Brazil, forming what is known as the "Brazil Current." This is traceable Southwards, at a gradually diminishing rate, as far as the estuary of the Rio de la Plata, in S. Lat. 35° , where it appears to turn to the eastward and to recross the Atlantic, forming what is known as the "Southern Connecting Current," which enters the South-African Current near its commencement, and thus completes the comparatively simple circulation of the South Atlantic. The Thermal effect of this southward direction of a portion of the *Equatorial* Current shows itself in a very marked manner in the deflection of the February (or *summer*) Isotherm of 80° nearly as far south as Rio Janeiro, so as to approach the February Isotherm of 75° within *eight* degrees on the meridian of 30° W.; although on the meridian of 20° W. these two Isotherms are *twenty-five* degrees apart. Yet notwithstanding this decided evidence of the thermal power of the *Brazil* current, its warming influence does not seem to extend itself in any considerable degree beyond the parallel of 30° S.; along which we find the February Isotherm of 75° and the August Isotherm of 65° running almost coincidently, until they bend northwards

* 'Directory for the Pacific Ocean,' vol. ii. pp. 1243-7.

under the influence of the *South-African* current. The February Isotherm of 70° and the August Isotherm of 60° follow a nearly similar course about 5° further South; as do the February Isotherm of 65° , and the August Isotherm of 55° near the parallel of 40° S. The marked regularity in the distribution of these lines and in their seasonal movements, as compared with the strong deflection of the Isotherms to the north of 30° S., seems to indicate that the Thermal influence of the Brazil current dies out sooner than its moving force; and this, it seems probable, may be attributed to the circumstance that its superheated stratum has only the ordinary thickness of that of Oceanic water, whilst in the Gulf-stream the excess of heat extends to a much greater depth (§ 127). For it is obvious that the thinner the superheated stratum, the more speedily will its temperature assimilate itself to that of the overlying Atmosphere; and that such is the case with the Brazil current, appears from the comparatively small southward deflection of the August (winter) Isotherms of 75° and 70° , while the Southern Isotherm of 80° moves northwards in that month, so as in September to be found wholly to the *north* of the Equator, continuing so in great part through October and November.

124. In our examination of the course of the Isotherms of the North Atlantic, it will be convenient to restrict ourselves, in the first instance, to that portion of it which, with the large contribution supplied by the Equatorial Current from the southern side of the Equator, becomes the feeder of the Gulf-stream.—In February and March, the northern Isotherm of 80° follows pretty closely the northern boundary of the Equatorial Current; but it does not extend into the Caribbean Sea, the general temperature of which during those months does not seem to be above 76° , or about the average of that of the open ocean between the same parallels. In the Gulf of Mexico the surface-temperature falls still lower, especially within the area over which the comparatively cold water brought down by the Mississippi diffuses itself; the temperature of the head of the Gulf being thus reduced even below 70° .—Now since it is at this period of the year that the temperature of the Southern portion of the Equatorial Current is at its highest, averaging about $81\frac{1}{2}^{\circ}$, it is obvious that the surplus heat which it carries towards the Caribbean Sea and the Gulf of Mexico is for the most part dissipated before its water re-issues into the Atlantic as the Gulf-stream. This will be seen to be a fact of some importance with reference to the Thermal effect of the Atmosphere upon the surface-temperature of the Sea.—The February and March Isotherm of 70° between the meridians of 35° and 75° W. keeps very close to the parallel of 28° N., passing directly across the area of the Sargasso Sea; east of Long. 35° , however, it bends southward, under the influence of the colder North-African current; whilst to the west of Long. 75° it turns abruptly to the North, under the influence of the Gulf-stream, which issues from the Florida Channel during these months at a temperature of about 75° . Impinging, as it were, on the Isotherm of 70° , the

warmer Stream carries it northwards as a loop, which, however, stops in February at Cape Fear (N. Lat. 34°), and in March at Cape Hatteras (N. Lat. $35\frac{1}{4}^{\circ}$); and thus we see that instead of carrying far into the North Atlantic the temperature of the Equatorial current, the Gulf-stream has lost thus early *more than ten degrees* of the heat which its water possessed when it crossed the Equator, and is *only five degrees* warmer than the sea through which it flows.

125. Very little change takes place during March and April in the general position of the Isotherm of 80° ; but the temperature of the Caribbean Sea and of the Gulf of Mexico rises considerably, so that the Gulf-stream in May issues from the Florida Channel at the temperature of nearly 80° . The Isotherm of 70° moves northwards with the approach of the Sun to the Tropic of Cancer; but the looped bend in its western portion occasioned by the Gulf-stream still stops at about 37° N. Lat. From June to September, however, the northward range of the Isotherm of 80° extends on its western side over the Caribbean Sea and Gulf of Mexico; whilst it also includes a considerable part of the Sargasso Sea, ranging to the north of the Bermuda group and approaching the American coast off Cape Hatteras. The Gulf-stream during these months issues from the Florida Channel at an average surface-temperature of about 83° , which is *higher* than that of the Equatorial current at its entrance into the Caribbean Sea; and for this there is no difficulty in accounting, when we bear in mind the fact that the Sun shines vertically on the Tropic of Cancer at the Summer solstice. There is nothing special, however, in the surface-temperature of the Caribbean Sea and Gulf of Mexico at this season; for that of the outside Atlantic between the same parallels, though in no way influenced either by the Equatorial current or by the Gulf-stream, is just as high. In the *eastern* portion of the Atlantic, however, the Isotherm of 80° is greatly deflected towards the Equator, not merely by the colder North-African current, but also, it would appear, by the southward flow of that portion of the Gulf-stream which passes round the Azores to return into the Equatorial current (§ 147).—Thus the surplus heat which the Gulf-stream carries northwards during the summer months is not that of the Equatorial region, but that of the northern Tropical region; and we shall presently see (§ 142) that the slow dissipation of its surplus Heat in this part of its course is due to its near equality in Temperature with the Sea and Air through which it passes for a considerable distance.

126. From October to January, on the other hand, there is a progressive return towards the conditions indicated by the course of the Isothermal lines for February and March; with this difference, however, that while the January Isotherm of 70° for the most part lies south of 30° N. Lat., and does not range further north than Cape Hatteras, the Isotherm of 80° extends, in the course of the Equatorial current, into the southern part of the Caribbean Sea. Thus as the temperature of the Gulf-stream at its

exit, during the months of November, December, and January, is about 76° , there is a *loss of heat of about four degrees* in the passage of the water that feeds it from the *north* coast of South America to the *south* coast of North America.

127. *Thermal condition of the Gulf-stream, and its influence on that of the North Atlantic.*—In considering this part of the subject, we have first to inquire whether the Thermal condition of the Caribbean Sea and of the Gulf of Mexico, which last constitutes the head-water of the Gulf-stream, differs in any essential condition from that of the outside Atlantic: and on this point we derive important information from a series of Thermometric observations recently taken in the New York School-ship 'Mercury,' which show that a very close correspondence in *surface-temperature* may veil a considerable difference between the temperatures of the underlying stratum.—The 'Mercury' crossed the Atlantic in the month of March from Sierra Leone to Barbadoes, running before a nearly steady E.N.E. Trade-wind, with an Atmospheric temperature ranging from 77° to 83° , the surface-temperature of the Sea ranging from 75° to 80° . At a depth of 100 fathoms, the temperature was 62° ; while at 200 fathoms it was found to be everywhere (save in comparatively shallow water, § 9) between 51° and 53° , the mean of eight observations being exactly 52° . Having proceeded from Barbadoes to St. Thomas, the 'Mercury' sailed, during the first fortnight of April, along the southern side of Porto Rico, St. Domingo, and Cuba, finding deep water everywhere; and then, rounding the western extremity of Cuba, she made her way northwards through the Florida Channel. Now in this part of the course, the temperature of the Air ranged from 80° to 84° , and the surface-temperature of the Sea from 83° to 86° , showing a considerable elevation, which is probably attributable to the influence of the *Equatorial* current, this being at its hottest in March and April. But a still more marked excess shows itself in the temperature of the stratum beneath; for at 100 fathoms the temperature was found to be 72° , and at 200 fathoms 62° (in both cases *ten degrees* above the temperatures at corresponding depths in the outside Atlantic), at 300 fathoms 54° , at 400 fathoms 50° , and at 500 fathoms 48° .—This, as it seems to me, is an indication that the partial separation of the Caribbean Sea from the Basin of the Atlantic produces somewhat the same effect upon the temperature of its deeper water, that is shown in a much more remarkable degree in the Mediterranean (§ 10); for if the bottom-inflow of Polar water be impeded (though not altogether prevented), the temperature of the whole mass of the water that is not directly subjected to solar influence will of course be proportionally higher*.

* It is remarkable, however, that on the Mosquito Coast,—where a very high surface-temperature usually prevails,—the sub-surface temperature seems to correspond more closely to that of the outside Atlantic; the following observations being given by Capt. Maury from the journals of Mr. Dunsterville:—at 240 fathoms, 48° ; at 386 fathoms, 43° ; at 450 fathoms, 42° . This difference is perhaps attributable to the much

128. We have next to inquire what is the Thermal relation of the *Gulf-stream* to that of the basin from which it issues; and what indications are afforded by its Temperature at different Depths as to the Movement of its different strata.—In the first place it is essential to bear in mind that the southward extension of the *Polar Current* which impinges against the Gulf-stream on the Banks of Newfoundland has been very distinctly traced along the sea-board of the United States, as a distinct band of separation between the coast-line and the Gulf-stream, as far south as the Peninsula of Florida: for although its surface may be warmed by an overflow from the Gulf-stream (as, in the ‘Lightning’ channel, the glacial stream from the N.E. is overlain by the warm stream from the S.W.), yet its presence is distinctly indicated by the rapid descent of the thermometer at small depths beneath. Thus off Sandy Hook, where the distance of the Gulf-stream from the coast is about 240 miles (Diagram v. Plate V.), the temperature of the surface near the coast is 70° in summer, rises to 75° at about 150 miles distance, and to 83° at about 275 miles, where the section crosses the warmest band or axis of the Gulf-stream: but at a depth of only 20 fathoms in this intervening band, the thermometer falls to 60° ; at 100 fathoms it averages about 47° ; at 200 fathoms it is about 43° ; at 300 fathoms from 39° to 42° ; and at 400 fathoms from 37° to 40° . As soon, however, as the “cold wall” has been passed, the thermometer at 20 fathoms rises to 77° ; at 100 fathoms to 67° ; at 200 fathoms to 62° ; at 300 fathoms to 59° ; and at 400 fathoms to 55° or even 58° .—The breadth of the Polar Stream gradually diminishes, and the rate of its movement decreases; but that it preserves a steady onward flow is proved by its continuity of temperature, which is distinctly traceable along the whole length of the Floridan Peninsula, from Cape Canaveral, where its breadth is about 35 miles, into the Florida Channel itself. For here the Gulf-stream is separated from the American shore-line by a band about 10 miles broad, in which the temperature falls within 100 fathoms to 50° , whilst in the axis of the Stream it averages 75° at that depth; and very distinct evidence of the *inward* movement of this colder band is afforded by the fact, first pointed out by Prof. Agassiz* and since verified by Capt. E. B. Hunt (of the U.S. Engineers), that the Florida Keys and Reefs are slowly but steadily extending *westwards*†. During rough weather, the sea about the reefs becomes milky from the stirring-up of the deposit at the bottom; and this “white water” is invariably drifted to the westward, the matter it carries being slowly deposited both north and south of the

freer and more direct communication which exists between the deeper parts of the *southern* portion of the Caribbean Sea and of the outside Atlantic, than that which its *northern* portion possesses.—Further inquiry into the sub-surface temperature of different parts of the Caribbean Sea and the Gulf of Mexico is much to be desired on various grounds.

* U.S. Coast Survey Report, 1851; and Appendix 10, p. 145, 1860.

† Silliman's American Journal, vol. xxxv. pp. 197–210 & 388–396.

line of Keys, and 30 or 40 miles to the southward of them. That the inward counter-current, of which this fact affords evidence that may almost be called demonstrative, occupies not only that shallower portion of the channel which follows the coast-line of Florida, but the lower portion of the deepest part of each section, where it underlies the axis of the outflowing Gulf-stream, will be presently shown to be an equally certain inference from the Temperatures met with at different depths in each Section, from the surface downwards (§§ 129-133).

129. It is on the line of Section taken by the United States Coast Survey in 1866, between the Dry Tortugas and Havana (see Diagrams iv., vi., Plate V.), that our detailed knowledge of the Gulf-stream commences. The breadth of this channel is about 82 miles; and its maximum depth, which is met with at about 37 miles from the Cuban shore, is 845 fathoms. On the northern side, the bottom lies in terraces, which are nowhere abrupt; but on the southern side, about halfway between the deepest part and the Cuban shore, there is a steep ridge rising about 400 fathoms from the sea-bed, so as to come to within about 350 fathoms from the surface. The course of the bathymetrical Isotherms in the different parts of this Section is very remarkable. Instead of lying parallel to the surface, they follow the contour of the bottom; *the colder water being found much nearer to the surface in the shallower than in the deeper portion of the channel.* The following is the bathymetrical range of these lines at intervals of 5°:—

Temperature.	Range of Depth.
75°	20 to 130 fathoms.
70°	60 to 180 "
65°	75 to 250 "
60°	90 to 320 "
55°	150 to 380 "
50°	200 to 440 "
45°	350 to 500 "
40°	480 to 550 "
35°	580 to 600 "

Thus it appears that the lower half of this channel is occupied by water whose temperature is below 50°; and that this colder water is thrown up in the shallower parts of it to within 200 fathoms of the surface. Looking to the steady diminution of temperature with depth, until a temperature of 35° is reached at about 600 fathoms, it can scarcely, I think, be questioned that the whole of the water below the bathymetrical Isotherm of 50° is an *inward* prolongation of the Polar Stream; the *outflowing* Gulf-stream being limited to the stratum of 60° or upwards. This limitation was indicated also by the deflection of the sounding-line occasioned by the current; which led the U.S. Surveyors to the conclusion that the outwardly moving stratum has not above *one third* of the actual depth of the channel.

In the northern half of this section, above the terraces south of the Florida Reefs, the water lies almost motionless; and the eastward flow of the Gulf-stream is limited to the deeper southern half of the channel.

130. Proceeding about 120 miles to the eastward, we find that while the channel (between the Sombrero Lighthouse and the Salt Key Bank) is narrowed to 45 miles (see Diagram iv.), and its maximum depth is reduced to 600 fathoms, the evidence of a division between two strata is still more distinctly marked by the course of the bathymetrical Isotherms (Diagram vii.). The northern slope, as in the previous instance, is the more gradual, the depth being only about 120 fathoms at a distance of 13 miles from the American shore; and here we find that while the temperature at 50 fathoms is 75° , so rapid a reduction shows itself with increase of depth, that the bottom at 120 fathoms is below 50° . In mid-channel, on the other hand, where the depth is the greatest, the line of 50° sinks to 175 fathoms, while towards the Salt Key Bank it is found at 200 fathoms; and the whole mass of water that occupies the deeper portion of the channel has a temperature below 50° , the thermometer showing 45° at 250 fathoms, 40° at 350, and 35° at less than 400.—Thus it seems clear that the colder water which underlies the warm Gulf-stream surges up on the shallower bottom of the northern side of it, so as to rise to within 120 fathoms of the surface, though overlain by a thin stratum of water having nearly the temperature of the Gulf-stream proper.

131. After passing Sombrero Lighthouse, the channel of the Gulf-stream begins to turn northwards (Diagram iv.): and the next line of section, taken between Carysfort Lighthouse and the Great Bahama Bank (Diagram viii.), shows it to have somewhat widened and at the same time become shallower. The total breadth of the channel is here about 60 miles; but of this, a band of about 15 miles broad on the Florida side appears to be occupied by the Polar Stream. The maximum depth in mid-channel is about 500 fathoms; and the portion of it that exceeds 400 fathoms in depth is about 35 miles broad. The general character of this section very closely approximates to that of the Havana section, except that the slope of its banks is more equal. It is only on the American side, however, that the Isotherms down to 50° run upwards, showing the approach of the colder water to the surface. Thus the temperature of 55° is there found at 125 fathoms, whilst on the other side it is not reached at 250. At 350 fathoms in mid-channel, the temperature is below 50° , and in 60 fathoms more it is reduced to 40° . Although the temperature does not seem to have been observed at depths much greater than 400 fathoms, it can scarcely be doubted that it would be found as low as 35° in the deepest part of this channel, as it is at a less depth in the Sombrero section.

132. The channel again contracts, and at the same time diminishes in depth, as far as Cape Florida (Diagram iv.), between which and the Bemini Isles its sectional area is smallest: for, while its whole breadth is not much

more than 40 miles, the Polar stream occupies 15 miles of this breadth on the Florida side; and while its greatest depth scarcely exceeds 300 fathoms, even this excess only extends over a breadth of about ten miles, forming a valley on either side of a submarine ridge (Diagram 1x.). The Florida slope shows a well-marked succession of terraces, whilst the Bemini slope is very steep. It is most singular to see how the bathymetrical Isotherms here follow the undulating contour of the bottom, instead of lying parallel to the surface; plainly indicating that the colder and heavier water has a motion of its own, by which it is carried up the slopes of the hills, instead of finding its level in the valleys. The 75° line, which lies at the surface on the Florida side, sinks to nearly 100 fathoms in the deepest part of the channel; and at ten miles from Cape Florida, where the whole depth but little exceeds 160 fathoms, the water has a temperature of 70° even at 75 fathoms, clearly showing the extension of the warm stratum to that side of the channel. But below 75 fathoms, on this terrace, the temperature falls so rapidly, that 45° is reached at 140 fathoms; though in the deeper channel the water at that depth has a temperature of 65°, sinking to 45° at 250 fathoms. No temperature below 45° is recorded as having been observed in this section; but if the rate of bathymetrical reduction between 200 and 250 fathoms be continued downwards to a bottom below 300, the temperature of the lowest stratum will be found as low as 35°.

133. Although the temperature of 35° was not actually observed either in the Carysfort or in the Bemini sections, the fact that it showed itself in the deepest water of both the Sombrero and the Tortugas sections, and in the latter at a depth of less than 400 fathoms,—taken in connexion with the difficulty, if not the impossibility, of otherwise accounting for the presence of water of 35° within the Narrows,—seems fully to justify the assumption that it has flowed over what may be called the submarine watershed between Cape Florida and the Bemini Isles; and it is clear that in so doing it must have flowed up a very considerable ascent, which it could only do in virtue of a constantly acting propulsive force. This is strikingly shown in Diagram 111., Plate IV., which represents the longitudinal course of the bathymetrical Isotherms of 50°, 45°, 40°, along the axis of the Gulf-stream in its passage through the Florida Channel.—The soundings taken in the subsequent course of the Gulf-stream do not anywhere give the depth at which temperatures below 45° exist beneath it; but as that temperature is reached in the Polar current at 200 fathoms, while the thermometer sinks at 300 fathoms to 40°, and at 400 fathoms to 38°, it seems clear that the water occupying the lower stratum of the Florida Channel is derived from the same source.

134. That the Polar current which passes into the Gulf of Mexico beneath the outflowing Gulf-stream is due to the excess of density in the outside column, depending on the depression in the temperature of its lower stratum, was maintained in 1867 by Mr. Mitchell*, who had been engaged in the

* Silliman's American Journal, vol. xliii. (1867) p. 74.

survey of the Tortugas section, and reported very carefully on the phenomena it presents. He regards the Gulf-stream current, like that of the Baltic or the Dardanelles, as tending to the restoration of the surface-level of the basin from which it flows, which the inset of the Equatorial current will as constantly tend to raise; and he gives the following example of "compensating currents," which is peculiarly applicable not merely to the doctrine now under consideration, but also to that of the under-currents of the Straits of Gibraltar and the Baltic Sound.—During the dry season (July), the surface-outflow of brackish water through the Narrows of New York harbour occupies *nine* out of the twelve tidal hours; this water chiefly consisting of the water brought down by the Hudson River, with some admixture of salt water. This salt water enters as a lower stratum, the *inflow* of which is nearly uninterrupted, though not constant in velocity; and the same condition extends for some distance up the river. On running a line of levels from New York City to Albany, it was found that the bed of the Hudson lies below the mean level of the sea for nearly 100 miles from its mouth; but that the surface of the fresh water, even in the dry season, is above this level,—not so much so, however, as to equalize the difference of weight between the column of River-water within the Narrows and that of the Sea-water outside; so that the latter during the summer months flows in along the bed of the stream, while the former overflows into the ocean. During other parts of the year, however, the level within the Narrows being higher, the inner column is the heavier, and the inflow of Sea-water does not take place.

135. We are now prepared to examine the influence of the body of warm water discharged by the Gulf-stream into the Mid-Atlantic, on the Temperature of the Oceanic area through which it makes its way.—It is obvious that so long as it retains its Northern course, and does not diffuse itself to the East—while it is completely shut in on its Western border by the Arctic current—it cannot directly affect the temperature of the general surface of the Ocean west of the Meridian of 70° ; and we find (as already pointed out) that the Winter Isotherms of 70° and 65° are only carried northwards in the immediate course of the Stream, while the great northward movement of the Summer Isotherms of 80° and 75° appears to be quite sufficiently accounted for by the general influences already referred to (§§ 117–119) as modifying the climate of the North Atlantic.

136. The most striking peculiarity in the Thermal condition of the Gulf-stream, as compared with that of the Ocean through which it flows in the first part of its course, seems to consist, not so much in its more elevated surface-temperature, as in the greater thickness of its superheated stratum; which, as will be presently shown, has a most important influence on the maintenance of its surface-temperature when it is exposed to an atmosphere colder than itself. Recent inquiries have shown that the high surface-temperature of the Gulf-stream is not derived (as commonly supposed) from its circulation within the almost land-locked Gulf of Mexico; for the average

surface-temperature of the Gulf of Mexico is usually *lower* than that of the Caribbean Sea, and during several months in the year it is rather *below* that of the Gulf-stream in the Florida Channel (§ 124). Hence the surface-layer, at least, of the Gulf-stream would appear to be derived from that warmer current which, after flowing westward along the south of Cuba, turns abruptly round Cape Antonio, and then flows eastward towards the Florida Channel.—But we might expect that the Gulf of Mexico, even more than the Caribbean Sea, would have its *sub*-surface temperature elevated by the limitation to the admission of Polar water; and such an elevation we find to be presented in the section between the Tortugas and Havana, which may probably be considered, as regards this stratum, to represent the Gulf of Mexico generally. Accordingly, on comparing its thermal condition (§ 129) with that of the corresponding stratum of the Caribbean Sea, as shown in the temperature-soundings of the 'Mercury' (§ 127), we see that the temperatures between 100 and 400 fathoms are a few degrees *higher* in the Tortugas section than in the Caribbean Sea; the temperature of 62°, which extends in the former to 300 fathoms, ranging in the latter only to 200. But even this downward range contrasts strongly with the limitation of that temperature to the uppermost 100 fathoms in the open Ocean, and the rapid fall in the next 100, as shown in the 'Mercury' soundings to the east of Barbadoes (§ 127). This downward extension of surplus heat is retained through all the early part of the Gulf-stream; as has been already shown in the contrast between the temperatures of the Polar Current and of the Gulf-stream off Sandy Hook (§ 128).

137. It can scarcely be doubted that the extraordinary thickness of the superheated stratum in the Gulf-stream has much to do both with its own retention of a high surface-temperature in its northward course and with its power of imparting heat to the Air above it; for it is obvious that the thinner the superheated stratum, the more speedily will its temperature be brought down by that of a colder superincumbent atmosphere. But it is also clear that its loss of heat may be really much greater than the reduction of its surface-temperature would indicate; for as fast as its superficial stratum is cooled down, its increase of density will cause it to sink until it meets with water as cold as itself, the warmer sub-surface stratum rising into its place. And since this process will continue to take place so long as there is a subjacent stratum of higher temperature than the superincumbent Atmosphere, the *surface*-temperature of the current may be maintained with comparatively little reduction, though the temperature of its subjacent strata may have been reduced almost to that of the ordinary Oceanic water which it overlies. But in the very same proportion that it thus *loses* heat, will it *impart* heat to the Atmosphere above; and may thus, by warming a vast body of air which is rapidly borne towards North-western Europe, furnish an important element in the amelioration of its climate.—The dependence of the retention of a high surface-temperature on the thickness of

the superheated layer is well shown in the contrast between the Mediterranean and the portion of the Gulf-stream that lies between the same parallels. For while the surface-temperature of the former sometimes rises as high as that of the latter, it is subject to a considerable *diurnal* range, in consequence of the thinness of its superheated stratum ; while its *seasonal* range closely follows the temperature of the atmosphere, down to its constant winter mean of about 54° (Report for 1870, § 89). But in the latter there is scarcely any diurnal range ; while its winter temperature only falls to 72° off Cape Hatteras, and to 67° off Nantucket ; for as a temperature of 60° or upwards extends to a depth of from 200 to 300 fathoms, the whole of this *sub-surface* stratum must be reduced to that standard, or below it, before the *surface*-temperature would fall to 60° .—It follows as a Corollary, that a *deep* stratum having a moderate excess of temperature may be a far more effectual carrier of Heat into a colder area than a much warmer superficial flow.

138. The *thermal power* of the Gulf-stream, or of any similar Current, must depend on three factors,—(1) the *Sectional Area* of the Stream ; (2) the *Rate* of its flow ; and (3) its *Temperature*.

139. It is impossible, in the present state of our knowledge, to arrive at any exact estimate of the *sectional area* of the Stream ; since it is for the most part only from the Temperatures of its different strata that we can judge whether they are, or are not, in movement, and what is the direction of their movement. If we accept the conclusion of the U.S. Surveyors (§ 129) that in the *Havana* Section the depth of the *outward* current was not above one-third of the greatest depth of the Channel,—namely, about 200 fathoms,—and take the average temperature at that depth to be about 60° , we may assume that the stratum extending downwards to 60° in other sections represents the real outwardly flowing Stream. Now it will be seen that in the Cape Florida and Bemini Section, the line of 60° in the channel of the Gulf-stream proper has an average depth of about 175 fathoms, or 1050 feet ; but the breadth of the outflowing Stream cannot be taken (according to Prof. Bache's estimate) at more than 25 miles.—Mr. Croll's estimate of the quantity of water as equal to a stream 50 miles broad and 1000 feet deep, appears to be based on the sectional area of the entire channel, which he states at 30 miles broad and 1950 feet deep ; but it seems clear that the lower portion of this channel must be occupied by an *in-flowing* current ; and the only question is with respect to the depth at which the reversal of the flow takes place.

140. The *mean annual rate* of the Gulf-stream current is estimated by our Meteorological Department, on the basis of a large body of observations taken at various periods of the year, at not more than *two miles* per hour, or 48 miles per day, even in the "Narrows" where the current is most rapid. The rate stated by Mr. Croll, namely *four miles* per hour, is only seen at the period of the greatest strength of the current.—But the rate given by *surface*-observations affords no indication whatever of the rate o

movement in the sub-surface stratum ; and all our knowledge of double currents would lead to the belief that it gradually diminishes from above downwards, until the water becomes motionless, or nearly so, as we approach the plane of reversal. Hence, taking the medium between *two* miles and *zero*, the *average rate* of the whole outflowing stream would be no more than *one mile* per hour.

141. If we assume the limit of the stratum above 60° as that of the real Gulf-stream current, we shall find its *average temperature* to be somewhat higher than it has been stated by Mr. Croll, who seems to have taken 65° as the average of the water flowing through the *entire* channel. The average *surface-temperature* of the Florida Channel for the whole year is 80° ; and we may fairly set the average of the entire outgoing Stream, down to the plane of 60° , at 70° , instead of 65° as estimated by Mr. Croll.

142. The prevalent doctrine, however, of the persistence of this Temperature, with but very trifling reduction, nearly as far as the Banks of Newfoundland, is based on observations made during the Summer; when the Isotherm of 70° extends north of the parallel of 40° , and the cooling influence of the atmosphere is consequently at its least. In Winter, on the other hand, when the Isotherm of 60° follows nearly the same line, the surface-temperature of the Gulf-stream is reduced almost to that degree before it reaches the Banks; as is shown in the following Table, derived from the Admiralty Chart:—

	Winter.	Spring.	Summer.	Autumn.	Mean of Year.
Gulf of Mexico	73°	77°	83°	80°	$78\frac{1}{4}^{\circ}$
Florida Channel	77	78	83	82	80
Off Charleston	75	77	82	81	$78\frac{3}{4}$
Off Cape Hatteras	72	73	80	76	$75\frac{1}{4}$
S.E. of Nantucket Shoals . .	67	68	80	72	$71\frac{3}{4}$
South of Nova Scotia	62	67	78	69	69

Thus it appears that instead of a loss of only 5° in the northward flow of the Gulf-stream from Lat. 25° to Lat. 35° , the average loss for the whole year is 11° . And the cooling influence of the superincumbent Air on the Gulf-stream, *even at its deepest and strongest*, is manifested in its loss of 13° of surface-temperature in the Autumn, and of 15° in the Winter, although its passage thus far is accomplished in from forty to fifty days.— During this time, it must be remembered, it continues to lose heat by evaporation as well as by radiation; the large amount of vapour which is being continually given off being made manifest by its precipitation in the form of fog when the Gulf-stream encounters the Arctic current which meets it before it reaches the Banks of Newfoundland.

143. It is, again, on the contrast in Temperature between the Gulf-

stream and the Arctic current,—not between the Gulf-stream and the ordinary Oceanic water,—that the prevalent notions respecting its special heating-power are mainly founded. Thus Admiral Sir Alexander Milne, proceeding in H.M.S. ‘Nile’ from Halifax to Bermuda in May 1861, found the temperature 70° at the bow, when it was only 40° at the stern; thus showing a difference of 30° within the ship’s length. When, on the other hand, the temperature of the *eastern* edge of the Gulf-stream in the earlier part of its course, and of the *southern* edge in the later part of its course, is compared with the normal of the neighbouring portion of the Atlantic, the difference is found to be comparatively slight, the one graduating into the other.

144. The average rate of two miles per hour, which the Gulf-stream in the Narrows, is maintained to Lat. 30° ; but it then begins to show a decided reduction, falling to 40 miles per day between 30° and 33° N. Lat. When the Stream has passed Cape Hatteras, and its land side is pressed on by the Arctic current, this compression seems to have the same effect in increasing its velocity that limitation between banks would exert; for the rate of flow there rises again, sometimes exceeding *four miles* per hour. At the same time the rate of the Stream at its *outer* edge is not greater than from 10 to 20 miles per day. The direction of the Stream is gradually changed by the trend of the coast-line, first from N. to N.E. by N., then to N.E., and subsequently, after being subject to the influence of the Arctic current, to E.N.E. Part of this Easterly deflection, however, is probably to be attributed to the *greater* easterly momentum which this body of water brings with it from its southern source, in virtue of its excess of rotary velocity; as was first pointed out by Capt. Maury, whose view on this point was adopted by Sir John Herschel. And, of course, the further North the Stream advances, the more strongly will this excess show itself, in giving to the movement of the Stream an Easterly direction. Conversely, the Arctic Current coming Southwards will bring with it a *smaller* rotary velocity than that of the parallel it reaches, and will thus have a Westerly tendency, which will keep it close to the coast-line of the United States.

145. Very early in its course, the Gulf-stream begins to show a division into alternate bands of warmer and colder water; and these become very perceptible before it passes Charleston. The cause of this division appears to lie in the contour of the bottom in the Florida Channel; the elevations of which, as already stated (§ 132), throw up the colder water of the deeper stratum nearer to the surface. With the increase in the breadth of the Stream as a whole, there is at the same time an increase in the distance between the bands. Thus at Cape Hatteras, where the “cold wall” separating the Gulf-stream from the Arctic Current is 30 miles from shore, the first or axial band of the Gulf-stream has a breadth of 47 miles; to the east of this there is a cold band 25 miles broad; and this is succeeded by another warm band of 45 miles. These two warm bands, with the intervening colder band, are considered by Prof. Bache as constituting the

Gulf-stream proper; but to the east of this, beyond another cold band of 37 miles breadth, there is still another warm band 75 miles broad.—Off Sandy Hook, where the Stream makes its great bend to the East, and the “cold wall” is at a distance of 240 miles from the shore, the “Gulf-stream proper” has only increased in breadth from 117 miles to 127; but the breadth of the second cold band has now increased from 37 miles to 60, whilst the breadth of the third warm band has diminished from 75 miles to 50; the outer portion of the Stream showing an obvious tendency to lose itself in the general mass of Oceanic water.—The *total* breadth of the Gulf-stream is stated by the American Surveyors to be 350 miles off Cape Hatteras, and 410 miles off Nantucket; but as the outer boundary is not well defined, these estimates are only approximative.

146. The difference in the rate of movement of these bands is probably one source of the discrepancy in the statements given by different authorities as to the rate of the flow of the Gulf-stream as a whole. It is commonly said to pass Nantucket at the rate of about *one* mile an hour; and an observation cited in Blunt's ‘Coast Pilot’ would give about 0·7 mile per hour as its rate between W. Long. 57° and $55\frac{1}{2}^{\circ}$, between the 41st and 42nd parallels of Latitude. Many degrees to the east of this, however, a very rapid current—running at the rate of even *four* miles an hour—has been occasionally observed; and this is probably due, like that sometimes seen off Cape Hatteras, to the lateral pressure exerted by the Arctic current, which comes down in full force over the Banks of Newfoundland, sometimes extending far to the southward, directly into the course of the Gulf-stream. It is during the early months of the year that, under the influence of the N. and N.W. winds which then prevail along the coast of Labrador, the Arctic current—bringing with it immense fields of polar ice—is at its strongest; and the Admiralty Chart shows the southward extension of this field-ice, between March and July, reaching even to the 42nd parallel between the meridians of 55° and 45° W. Long.; while between April and June, icebergs range as far South as 39° between the meridians of 50° and 40° . This enormous body of Polar ice-laden water must have a powerful influence both on the movement and on the temperature of the Stream against which it impinges, more especially since the deep-floating icebergs will bring this influence to bear directly on its deeper strata; and it is considered by Mr. Findlay that “by the time the Gulf-stream “has reached this limit, its original character is so thinned out and expanded, and its specific character is so destroyed from this cause, and “from the neutralizing effects of the Labrador currents, that it can no “longer be recognized beyond this cold-water gulf, which cuts off, as it “were, its further progress, and which, it is manifest, it can neither bridge “over nor pass under.” (Proc. Roy. Geogr. Soc., Feb. 8, 1869, p. 107.)—That the Stream has here for the most part thinned-out to a comparatively shallow stratum running over much colder water, is indicated by the observations of Capt. Chimmo (*Op. cit.* p. 92 *et seq.*), which were made

in July 1868, on the axis or northern border of the Gulf-stream. Thus near the southern edge of the Grand Bank, the temperature of the surface being 65° , it was found to be only 50° at 100 fathoms; and a large iceberg was met with as far as 30 miles south of the Grand Bank, showing the southward extension of an *underflow* of Arctic water, although the surface-temperature of 62° indicated that the upper stratum consisted of Gulf-stream water flowing in a very different direction. "Although it was still 150 feet high, and nearly 400 immersed, it was quickly and perceptibly undermining, decomposing, splitting with loud reports, and floating away in large portions with the easterly current." In another instance, the surface-temperature being 61° , the temperature at only 50 fathoms depth was as low as 43° ; but there was here probably a mere overflow of the surface-stratum, corresponding to that which extends beyond the "cold wall" off the coast of the United States (§ 128). That there is still a warm band extending to a considerable depth, seems to be indicated by the sounding taken in Lat. $43^{\circ} 30' N.$ and Long. $38^{\circ} 50' W.$ to test the existence of the supposed "Milne Bank." Here the surface-temperature being 73° , the temperature at 100 fathoms was 62° , and at 300 fathoms was 55° ; and thus, although the temperature of the upper stratum was nearly ten degrees lower than that which it showed off Sandy Hook (§ 128), the temperatures at 100 and 300 fathoms were nearly identical with those there found at corresponding depths, and were above those found at the same depths and under almost the same parallel nearer the coast of Europe (§ 13).

147. The direction of the Gulf-stream current is here so nearly due East, that we should naturally look for its continuation across the open Ocean in the same direction. After passing the meridian of $40^{\circ} W.$, however, we find the summer Isotherm of 75° , which rises between the meridians of 45° and $65^{\circ} W.$ to the north of the parallel of $40^{\circ} N.$, and the summer Isotherm of 70° , which rises to $43^{\circ} N.$, as well as the winter Isotherm of 60° , which nearly coincides with it, all tending *southwards*,—the first very abruptly, the second and third more gradually (Plate VII.); and this tendency corresponds with the general set of the surface-current. From the coincidence of these facts, there can be no reasonable doubt that a very large portion of the Gulf-stream here takes a Southward direction, passing first S.E. towards the Azores, and then due S. and S.W., so as to return off Cape Verde into the Equatorial Current,—thus completing, with the North-African Current (§ 120), the "shorter circulation" of the North Atlantic. This deflection of the Gulf-stream current seems dependent on an *indraught*, producing a "compensation-current" for the replacement of the water driven westward by the Trade-winds.

148. The question we have next to consider is,—What evidence can be adduced of the extension of any part of the Gulf-stream proper, on the Easterly line of direction which it retains on the Meridian of $40^{\circ} W.$, to the western coast of Europe? It seems to be now clearly established that

before reaching the Meridian of 30° W., the Gulf-stream, to use the language of Dr. Hayes, "has lost every distinctive character as a current: first, in "rate of flow, which has become that of the general easterly 'set' of the "Atlantic; second, in temperature, which has become that of the general "temperature of the air; third, in colour of water, which has lost the blue "that it had when merging from the Gulf of Mexico; in every thing, in "fact, which goes to make up what we designate as an 'ocean-current.'" This general Easterly "set," according to the Admiralty Chart, prevails over the whole area of the Atlantic between the parallels of 43° (Cape Finisterre) and 55° (Belfast), taking a more northerly direction in still higher latitudes. Its usual rate appears to be from 6 to 24 miles per day, varying with the degree in which the westerly "Anti-trades" predominate in force and duration over other winds. That it is essentially independent of the Gulf-stream, seems to be distinctly indicated by the fact that it commences from the very edge of the Arctic current, on the Eastern side of the broad band which it covers, as far as 10° to the north of the Gulf-stream, running parallel to its course. Although mainly due to the dominant influence of the "Anti-trades," yet it may be partly accounted for in another way; for if, as I have already argued (§ 13), the great body of *sub-surface-water* occupying this band has been drawn into it from a lower latitude, this water will tend (like that of the Gulf-stream itself, § 144) to move from West to East, in consequence of the excess of easterly momentum it has brought with it.

149. Now in the midst of this general Easterly "set," the only indication of any continued movement of the Gulf-stream in its original direction is the variable Current known as "Rennell's;" which, flowing Eastwards into the southern part of the Bay of Biscay, is then deflected in a north-westerly direction by the turn of its coast-line, so as to cross the Channel towards the Scilly Islands, and thence passes to the S.W. coast of Ireland. Though this is usually described as "a branch of the Gulf-stream," I look upon it as the principal continuation of that portion of it which does not turn southwards round the Azores; there being no apparent reason for a Northward deflection of its flow, and no indication of such deflection other than that which *surface-drift* is quite sufficient to account for. For this takes up and carries onwards any floating bodies which the Gulf-stream has transported into the Mid-Atlantic; and the fact that these are carried rather to the West of Ireland, the Hebrides, the Orkney, Shetland, and Faroe islands, and even to Spitzbergen, than in the direct Easterly course towards the Bay of Biscay which the Gulf-stream has when it ceases to be recognizable as a distinct Current, seems a clear indication that their transport over the latter part of their course is essentially due, as was long ago suggested by General Sabine (§ 88), to the predominance of South-westerly winds over this portion of the area of the Atlantic.—It is well remarked by Dr. Hayes, that just as a ball fired from a cannon stationed on the top of a hill loses its velocity with every second of its progress, and falls to the

earth when its impelling force is exhausted, but may still roll down hill by the force of gravity, which is a new power applied to it, so may Gulf-stream water, and any thing which it floats, be drifted onwards by the action of the Wind, after the propulsive force of the Gulf-stream has died out.

150. If, then, there be no other Mechanical evidence of the extension of the Gulf-stream proper to Western Europe, than that which is afforded by "Rennell's Current," we have next to inquire what evidence can be adduced of its influence on the Temperature of the Eastern side of the Atlantic.—This question can be best answered by an examination of the course of the Isothermal lines to the eastward of the Meridian of 30° . For their passage across that meridian between the parallels of 34° and 50° at more regular intervals than are seen between them elsewhere, indicates that their position is there comparatively little affected by disturbing causes, either of elevation or depression; and further, the close relation which we there observe between the Winter Isotherms and the Summer Isotherms of 10° higher, indicates that on this meridian the seasonal movement takes place rather in accordance with general Climatic changes than under any special influences. For the *Summer* Isotherms of 75° , 70° , 65° , and 60° are here nearly equidistant, crossing the Meridian in the parallels of 34° , 41° , 46° , and $50^{\circ}5$ respectively; while the *Winter* Isotherms of 65° , 60° , 55° , and 50° severally cross it at a distance of scarcely a degree from the preceding. Now whilst, as we have seen (§ 147), the summer Isotherm of 70° and the winter Isotherm of 60° turn *southwards* to the east of 30° W., the summer Isotherm of 65° and the winter Isotherm of 55° keep their course nearly due *eastwards* into the Bay of Biscay; while the summer Isotherm of 60° and the winter Isotherm of 50° in like manner keep an easterly course—a little tending to the north—towards the South of Ireland. There seems no reason whatever for believing that the ordinary temperature of the southern part of the Bay of Biscay is at all higher than the normal of the Latitude. Its winter temperature corresponds very closely with that of the Mediterranean at Toulon, which lies under the same parallel; while its summer temperature is much lower than that of the centre of Europe. We may, therefore, regard it as *ordinarily* out of the influence of the Gulf-stream; though a *band of water* possessing a temperature above that of the Ocean generally, is sometimes to be met with in a line which may be regarded as that of the Gulf-stream produced. Thus General Sabine, when proceeding, in January 1822, from Plymouth to Madeira, found the thermometer rise in crossing the Bay of Biscay from 49° in Lat. $47\frac{1}{2}^{\circ}$ to $55^{\circ}7$ in Lat. $44\frac{1}{3}^{\circ}$; an increase of $6^{\circ}7$ being thus shown between one day and the next, although the difference of Latitude alone would account for no more than $2\frac{1}{2}^{\circ}$. Further south the temperature was found as much *below* the normal as it here was *above* it. So again, Dr. Franklin, in his voyage, in November 1776, between the United States and France, found the temperature along the produced line of the Gulf-stream much higher than has subsequently proved to be usual; the thermometer standing at 62° in Long.

15° W., where subsequently, in August 1785, it only showed 66°. Further west, in the course of the Gulf-stream proper, great diversities are observable between the temperatures found at the same points in corresponding periods of different years*.—On the whole, then, it seems probable that the Gulf-stream varies considerably from time to time in force and in heating power; and that an extension of it into the Bay of Biscay may be sometimes distinguishable by local elevation of the Thermometer, although the *ordinary* temperature of the Atlantic as far north as the British Channel is in no wise dependent on its influence.

151. *Evidence of amelioration in the Climate of the British Isles, and of the region still further North, by a North-easterly flow of Oceanic water.*—It is when we pass northwards along the western shores of Europe, as far as the British Isles, that we first encounter, in the marked northward tendency of the Isothermal lines, especially in winter, an indication of *northerly* movement in the water of the North Atlantic. But it is important here to observe that the winter Isotherms of 55° and 50°, as laid down in Dr. Petermann's Charts, reach a considerably higher Latitude in the Meridian of about 25° W. than they do where they approach the coast of Europe in the Meridian of 10° W.,—the former, which nearly touches the parallel of 50°, turning south to Corunna in 44° N. Lat.; and the latter, which rises on that meridian to 54½° N. Lat., falling to 50° at the entrance of the British Channel. Now this may be taken as a very significant indication that the residual heat which the Gulf-stream may retain, after encountering the Arctic Current, is dissipated in the further passage of its water to the eastward. And the same inference may be drawn from the monthly averages of the observations of surface-temperature taken on board the Cunard Steam-ships between the South of Ireland and the Banks of Newfoundland; which show that while the winter (February) average only falls from 54° in W. Long. 40° to 53° in W. Long. 25° (although most of the change of Latitude occurs in that part of the course), it is reduced to 50° in W. Long. 10°. But the winter Isotherm of 45°, like the summer Isotherm of 55°, tends so continuously to the North, as to pass between the Shetland and the Faroe Islands; so that the whole western coast of the British Islands, having a range of more than *eleven degrees* of Latitude, lies between the July Isotherms of 60° and 55°, and the January Isotherms of 50° and 45°.

152. This northward extension of a Climate so little more severe than that of the South of England, bespeaks some very effective ameliorating agency; and the question now arises whether this agency is solely that of Wind, as maintained by Mr. Findlay and Dr. Hayes, or is in part exerted by Water. It is argued by Dr. Hayes that the temperature of the Sea follows, and is therefore *subject* to that of the Air, instead of *governing* it. Thus, he says, "We have seen and examined the Weather-register kept on "board the Light-ship off Sandy Hook. It shows that the temperature of

* See Rennell on Currents, pp. 276-283.

“the Water follows that of the Air with remarkable precision, whether on “the ascending or descending scale. The observations were made three “times daily, and they show a range throughout the year of from 29° “to 78°. This latter temperature was nearly as high as the highest temperature of the Air on that day. The lowest temperature of the Air “was 4°, which brought the water down to freezing, and some ice was “formed. The average temperatures for nine consecutive days in July “were—Air 74°, Water 71°; for a corresponding period in February, “Air 32°, Water 31°.” The following observations, again, are cited by Dr. Hayes to prove that comparatively warm water does not impart excess of warmth to the Air:—“At midnight, Feb. 22, 1869, the Pacific Mail-steamer ‘Alaska,’ on her way to Aspinwall, was 148 miles “to the north of the Gulf-stream; the temperature of the Air at the “time was 22°, and of the Water 39°, the ship steering south. At 2^h “50^m P.M., the Air was 39°, the Water 46°, which is the general Winter “temperature of the Ocean-water in that Latitude on the U.S. coast. At “2^h 54^m, the ‘Alaska’ having entered the Stream, the Air was 40°, the Water “65°. Afterwards the Water rose to 70°, but the Air remained at 40° until “the stream was crossed: then the Air rose to 44°, while the Water sank “to 62°.”—Dr. Hayes further cites, from a paper by Dr. Stork in the ‘Nautical Magazine’ for 1859, a series of observations which tend to prove that on the coast of Scotland the temperature of the Water of the Atlantic is regulated by that of the Air, rising and falling *after* it; so that the diurnal, monthly, and annual variations of the two show a close parallel, except that the fluctuations in the temperature of the Air are in advance of those of the temperature of the Sea.

153. This view, however, is in opposition to the results of the observations which have now been carried on by the Scottish Meteorological Society through a lengthened term of years*. For they show that on the West Coast of Scotland the *Mean Annual* Temperature of the Sea is from *two to three degrees higher* than that of the Air; whilst still further north, the difference is still more in favour of the Sea (§ 155). And they further show that this Mean Annual excess represents a very much larger *winter* excess; the *summer* temperature of the Sea being *below* that of the Air. For if we divide the whole year into three periods, each of four months, we find the average excess of Sea-temperature at Otter House, Loch Fyne, which is 2°·5 for the whole year, to be 6°·2 during November, December, January, and February, and to be only 2°·3 during March, April, September, and October; whilst during May, June, July, and August there is an average difference of 2°·1 in favour of the Air. These differences clearly show that the Sea here brings with it a temperature of its own, which tends to maintain an equability of Climate by moderating both

* “On the Temperature of the Sea between Scotland, Iceland, and Norway. By Dr. Keith Johnston and Alexander Buchan,” in *Journal of the Scottish Meteorological Society*, April 1871, p. 146.

the summer heat and the winter cold.—It would probably be found, however, on a more detailed comparison, that even in winter the relative temperatures of the Sea and Air are much influenced by the direction of the Wind ; as the greatest differences may be expected to present themselves when, after a continuance of S.W. winds which have produced a powerful drift of warmer water towards the coast *, the wind changes to the N.E., immediately reducing the temperature of the Air, and not for some time producing a like fall in that of the Sea.

154. It is further urged by Mr. Buchan, who has paid special attention to the Distribution of Temperature in the British Islands †, that the peculiar course of the *Isocheimal* lines, or lines of mean Winter temperature, indicates that the ameliorating influence comes from the *west*, rather than from the *south-west*, and thus from the Sea as well as from the Air. The course of the Isotherms between the months of April and October has a general relation to the parallels of latitude ; the summer-temperatures of Ireland and the West Coast being, however, *lower* in August (Plate VI.) than those of the middle of England, showing that the neighbourhood of the sea has a reducing effect at that period. In November, however, the direction of the Isotherms begins to undergo a marked change ; their western portions turning northward, and their eastern portions southward, whilst the intermediate parts run almost due north and south. Thus the Isotherm of 43° passes from Belfast across the Irish Sea to Whitehaven, and then turns southwards through Lancaster to Oxford ; while that of 45° , after passing Cape Clear and Wexford towards Anglesea, there takes a direct southward bend which carries it to Exeter. This meridional direction shows itself still more strongly in December,—the line of 42° , which passes through Belfast, turning southwards so as to pass through Liverpool and Bristol, and thence S.E. to Brighton and Dieppe ; while the line of 41° ranges nearly north and south from the Shetland and Orkney Islands to Dover, and that of 40° runs parallel to it from the Moray Firth to Cromer. It is in January, however, that this Meridional direction is most pronounced (Plate VI.),—the Isotherm of 39° passing from Unst along the Western coast of Scotland, and then through the centre of England to Hastings ; and the Isotherms of 38° and 37° lying parallel to it on the east, while those of 40° and 41° show a like parallelism to it on the west. In Ireland the Isocheimals “seem to envelope the island with their folds, which increase in warmth from the centre of the island outward to the ocean.” In February, however, the influence of the sun begins to show itself in the tendency of the Isotherms to exchange their meridional direction for that of the parallels of Latitude ; and this is still more marked in the March Isotherm, that of April showing the change completed. Now, as Mr.

* I learn from a friend who resides at Sidmouth, that the Sea-temperature always sensibly rises there with a S.W. gale.

† “The Temperature of the British Islands,” in *Journal of the Scottish Meteorological Society*, vol. iii. 1871, p. 102.

Buchan points out, if the warming influence were derived solely from Winds, the distribution of the Isocheimals or Winter Isotherms would be very different.

155. The recent extension, by the Scottish Meteorological Society, of the same accurate system of observations to the Faroe Islands and Iceland, and by the Meteorological Institute of Norway to various points on the Norwegian Coast, has brought out still more strongly the fact that the Climate of these stations is moderated, not merely by their proximity to the Sea, but by the warmer temperature, derived from a Southern source, which the Sea brings with it. At Thorsavn (Faroe), the Mean Annual excess of Sea-temperature, its maximum in the Winter months, and the reversal of the difference between the Air and Sea in the Summer, correspond closely with the similar averages on the West of Scotland. At Reykjavik the Mean Annual excess of Sea-temperature is a little higher, but the Winter maximum is not so great, and in the Summer the temperatures of the Sea and Air are nearly equal. At Stykkisholm the Mean Annual excess of Sea-temperature rises to $4^{\circ}2$; the higher average being due not so much to an increase in the Winter excess, but to the continuance of a sensible difference in favour of the Sea through the whole Summer, excepting in the month of May.—It is at the Norwegian Stations, however, that the excess of Sea-temperature shows itself most strongly, and particularly at Fruholm near the North Cape; where, the Mean Annual excess being $6^{\circ}1$, the mean excess of the four Winter months is $14^{\circ}5$ (that of December alone being nearly 17°), the mean of the four Spring and Autumn months being $6^{\circ}3$, while the excess of Air-temperature in the four Summer months averages only $2^{\circ}6$.

156. It can scarcely be doubted, then, that a general North-easterly surface-movement of Oceanic water is taking place in the portion of the North Atlantic which lies between Iceland and Scandinavia; and of the existence of such a movement adequate evidence has already been adduced (§14). This movement, says Admiral Irminger*, “is the cause why
“the harbours of Norway, even further than the North Cape, and as far
“as the Fiord of Varanger, are accessible for navigation during the whole
“year; just as the warm current which passes Cape Reikianäs, and runs
“to the northward along the western shores of Iceland, is the cause of the
“south and west coasts of this island being clear of ice, so that even
“during the severest winters ships may go to Havne Fiord and other
“places in the Faxe Bay of Iceland, where they will always be sure
“of finding open sea. If this current to the North in the Atlantic did not
“exist, the ice from the sea round Spitzbergen would float down to more
“southern latitudes than is now the case; and certainly the coasts of Nor-
“way, as well as the sea between Shetland and Iceland, would frequently
“be filled with ice from the Icy Sea, and the influence of the ice would
“then be felt on the climate of the neighbouring coasts.”—That this

* Proceedings of the Royal Geographical Society, May 10, 1869, vol. xiii. p. 227.

"slow current," however, is not a mere superficial drift, will appear from the considerations formerly stated (§ 13).

157. But independently of this general N.E. Oceanic movement, the Temperature-observations which have been correlated by Admiral Irminger*, and another series more recently collected and correlated by Prof. Mohn of Christiania†, indicate that its surface is traversed by *bands* of somewhat greater warmth. Admiral Irminger specially notes the existence of two such bands,—one of them a little to the west of Fair Isle, which is regarded by Dr. Keith Johnston and Mr. Buchan (on the basis of Prof. Mohn's data) as the axis of this "slow current," its temperature being sensibly higher than the temperature to the west or east of it; whilst the other, the position of which is more variable, is met with much further to the westward, sometimes even beyond the meridian of the southernmost point of Iceland.—These bands, the existence of which has been lately confirmed by Von Middendorf (§ 160), are regarded by Admiral Irminger (as it seems to me with great probability) in the light of real continuations of the "Gulf-stream proper," which are not only deflected northwards, but also carried onwards by the general N.E. "set." Admiral Irminger, moreover, without refusing to the "Gulf-stream proper" some share in the amelioration of the Climate of the regions towards which these bands proceed, distinctly expresses his conviction that this amelioration is mainly due to the heat brought by W. and S.W. winds from the "great and broad Atlantic Ocean."

158. Having thus found, in the Temperature-phenomena of the British Islands and of the Seas immediately adjacent to them, very decided indications of a general N.E. movement of Oceanic surface-water, we shall next trace the relation of these phenomena to the Thermal condition of the portion of the North Atlantic that extends from Newfoundland to the Arctic Sea, as indicated by the course of the Isothermal lines laid down in Dr. Petermann's Gulf-stream Charts for January and July. These show (Plate VII.) in a very marked manner the influence of the Labrador current, which bears southward a great body of Polar ice and glacial water, in depressing alike the summer and the winter Isotherms on the western side of the North Atlantic; the influence of this current in *lowering* the temperature of the portion of the Ocean in which it meets the Gulf-stream being probably fully as great as that of the Gulf-stream in *raising* it.—It is curious to see how sharply the *summer* Isotherms of $54\frac{1}{2}^{\circ}$, 50° , and $45\frac{1}{2}^{\circ}$ turn northwards to the east of the Banks of Newfoundland: diverging from one another and from the Summer Isotherm of 60° at intervals which are pretty nearly equal almost as far to the East as the meridian of 30° W.; but then again trending strongly to the North, so that the summer Isotherm of $54\frac{1}{2}^{\circ}$ crosses the parallel of 60° N. before, by a slight trend to the South, it passes through the Pentland Firth. Thence crossing the North Sea, this Isotherm passes along the coast of Norway as far as Tromsö (very near the parallel

* Journal of the Royal Geographical Society, vol. xl. (1870), p. 441.

† 'Température de la Mer entre l'Islande, l'Écosse, et la Norvège,' Christiania, 1870.

of 70°), and then turns southwards along the land, keeping within the coast-line of Russian Lapland, and passing across the narrow throat of the White Sea. The summer Isotherms of 50° and $45\frac{1}{2}^{\circ}$ cross the mouth of Baffin's Bay, and then follow the curve of the coast of Greenland towards Iceland; when approaching which they turn eastwards, the line of 50° striking the land at Stykkisholm on the N.W., while the line of $45\frac{1}{2}^{\circ}$ passes altogether to the north of the island. To the east of Iceland the Isotherms take a southerly bend, apparently under the influence of a drift of ice from the Polar Sea; but soon turn northwards again,—the line of 50° running nearly parallel to the coast of Norway as far as the North Cape, and then turning southwards along the coast of Russian Lapland, so as to cross the mouth of the White Sea to the base of the Kanin Peninsula; while the line of $45\frac{1}{2}^{\circ}$ runs parallel to this as far north as Lat. $72\frac{1}{2}^{\circ}$, and then turns southwards, still retaining the same parallelism, so as to strike the coast of Russia beyond that peninsula. Still further north, we find the summer Isotherms of 41° and $36\frac{1}{2}^{\circ}$ showing a nearly W. to E. direction until they have passed the meridian of 10° W., and then suddenly turning northwards; the line of $36\frac{1}{2}^{\circ}$ passing up to the west of Spitzbergen as far as 82° N., and also extending itself irregularly eastwards along the parallel of 75° as far as Nova Zembla.

159. The course of the *winter* Isotherms of $45\frac{1}{2}^{\circ}$, 41° , $36\frac{1}{2}^{\circ}$, and 32° , as shown in Dr. Petermann's Chart, is no less significant; for they all turn sharply to the North on the eastern side of the Banks of Newfoundland, cross the entrance of Baffin's Bay, and then keep a course of general parallelism to the coast of Greenland, crossing the meridian of 30° W. at almost equal intervals. The winter Isotherm of $45\frac{1}{2}^{\circ}$ follows almost exactly the course of the summer Isotherm of $54\frac{1}{2}^{\circ}$ as far as the Shetland Islands: but it then turns back on itself so as to form a loop, passing southwards along the Western Hebrides towards Belfast. The course of the winter Isotherm of 40° in like manner at first bears a general correspondence with that of the summer Isotherm of 50° , skirting the south coast of Iceland, and then passing N.E. in the channel between Iceland and Norway; but in Lat. $67\frac{1}{2}^{\circ}$ N. it also returns in a loop, which brings it back to the *east* coast of Scotland. The winter Isotherm of $36\frac{1}{2}^{\circ}$, again, corresponds very closely with the summer Isotherm of 45° ; passing through Iceland, and then keeping a N.E. course which carries it far to the north and east of the North Cape, when it, too, forms a loop bringing it back to the coast of Russian Lapland. Finally, the winter Isotherm of 32° proceeds along a similar course from the Banks of Newfoundland to the northernmost point of Iceland, and then onwards towards Jan Mayen, beyond which it has not been traced.

160. That this remarkable course both of the Summer and of the Winter Isotherms can only be accounted for by a N.E. flow of warm water, I am as strongly convinced as Dr. Petermann can be: and that this movement must be something very different from a mere surface-drift, seems to me

equally certain; since, unless the warm stratum is of considerable depth, it could not possibly retain that excess of temperature which it carries with it into high latitudes.—If any further evidence to this effect were wanting, it has been supplied by the recent observations made by Von Middendorf in the Voyage of the Russian Corvette 'Warjäg' between Archangel, Iceland, and Nova Zembla, in the summer of 1870*; some of the most important of which will now be cited:—

a. The existence of *alternating warm and cold bands*, as affirmed by Admiral Irminger, was confirmed. On the 17th of June, 1870, a temperature of $55^{\circ}6$ was observed off the coast of Norway, north of 60° ; and in July a temperature of $54\frac{1}{2}^{\circ}$ was observed in N. Lat. $69\frac{2}{3}^{\circ}$, nearly in sight of the islands off Tromsø, in N. Lat. 64° in the roads of Reikiavik, and in N. Lat. $61\frac{1}{4}^{\circ}$ on the meridian of the centre of Iceland. On the other hand, near the Lofoten Islands the surface-temperature fell to 4° ; and a minimum of $42^{\circ}1$ was observed in N. Lat. $64\frac{1}{2}^{\circ}$.

b. The *thickness of the warm stream* is shown by the fact that in N. Lat. $69\frac{1}{2}^{\circ}$ and W. Long. 14° , the surface-temperature being $50^{\circ}7$, the temperature at 40 fathoms was found to be still $46^{\circ}4$, and at 84 fathoms $45^{\circ}5$.

c. The North-Cape stream, hardly perceptibly cooled from $54^{\circ}5$, runs past the White Sea and the Kanin Peninsula toward the entrance of the Kara Sea; so that in the vicinity of Kolgujev Island (N. Lat. 68°) there are still bands which have in July nearly the same temperature.

d. On the meridian of the Kanin Peninsula, the North-Cape stream, which may be there called the Kanin stream, has a breadth of more than 2° of Latitude, with a range of temperature between 55° and $47^{\circ}7$. The higher the temperature is on the surface, the more rapidly does it fall beneath it; but at 30 fathoms it is still between 42° and $38^{\circ}7$. The Kanin stream appears to divide at Nova Zembla; its main branch going onwards into the Kara Sea, whilst a side branch turns northwards along the west coast of Nova Zembla. Another portion, however, striking against the Kanin Peninsula, seems to turn inwards along the east coast of the White Sea, the temperature of which is moderated by it (especially with N.E., N., and N.W. winds) as far as Dwina Bay. The western coast of the White Sea, on the other hand, is bordered by a cold stream, the temperature of which is probably the local temperature corresponding to the region. Thus, in passing round Cape Swätoi at the beginning of July, the thermometer fell to $42^{\circ}6$, and further *south* to $39^{\circ}9$; whilst a month later, $1\frac{1}{2}^{\circ}$ further *north*, on the same meridian, the temperature was $51^{\circ}1$.

e. It is considered by Von Middendorf that "the Gulf-stream can "still be detected at Kolgujev, not only by the temperature, but also by "the blue colour and high salinity of the sea."—"We sailed there "through water of so deep a violet-blue, that I was confident of finding it "swarming with microscopic animalculæ and plants. My astonishment

* Geographische Mittheilungen, Jan. 1871.

“ was great when I could not detect any thing under the microscope.”—As this distinctive blue colour has not been observed in the North-Cape stream, I should be disposed to attribute it to the diffusion of the fine sedimentary particles brought down by the Dwina and Mezen rivers (Report for 1870, §§ 98, 99). The Specific Gravity of the water of the Kanin stream being only 1.025, it is high only in relation to that of the water of the White Sea, which is reduced by the large quantity of river-water discharged into it. At Cape Swätoi, which does not lie in the supposed Gulf-stream, the Specific Gravity of the water was found to be 1.026.

f. The Zoological researches of Th. Jarshinski (1869) along the Murmanian (N.E. Lapland) coast of the Polar Sea, are stated by Von Middendorff to prove the affinity of its Fauna with that of the Atlantic Ocean.

g. The remarkable agreement of the temperature of the Air with that of the Water, and the manifest dependence of the temperature of the Air on that of the Water, induce Von Middendorff to adopt, without hesitation, the doctrine of direct heating by warm water. “ We should have been “ able,” he says, “ to determine by the temperature of the Air, without “ ascertaining that of the Water, whether we were or were not within the “ warm water of the extension of the Gulf-stream. The direction of the “ wind had evidently but a subordinate influence on the temperature of the “ Air.”—It is expressly stated by Von Middendorff, that when speaking of “ currents” he does not intend to imply more than the result of Temperature-observations, which indicate a flow of warm water from the west.

161. The Temperature-observations recently made by Messrs. Weyprecht and Payer (§ 15) in still higher Northern Latitudes, show that *this warmer surface-layer rapidly thins off towards the north-east*; and that instead of a rise of Temperature with increase of depth in the Polar area (which is the doctrine still maintained by many Physical Geographers), there is a rapid *reduction*,—glacial water being found at a less and less depth in proportion to the Northing obtained, as I ventured to predict in my last Report (‘ Proceedings,’ vol. xix. p. 190) would prove to be the case.

162. Further, the observations collected by Dr. Mühry* relating to the Temperature of the Western coast of Greenland, seem to indicate a northward flow of comparatively warm water along that side of Baffin’s Bay, in antagonism to the Polar current which flows southwards on the Labrador side. It is certain that the climate of the south-western coast of Greenland is much milder than that of either its eastern coast or the eastern coast of Labrador under the same parallels; and the summer Isotherm of 41° is carried northwards in Dr. Petermann’s Chart nearly as far as Upernavik, while the summer Isotherm of $36\frac{1}{2}^{\circ}$ extends in 70° W. Long. to Smith’s Sound, as in 10° E. Long. it extends to Spitzbergen. According to Admiral Irminger, a distinct current can be traced as far north as Lat. 64° or even 67° ; and this brings with it *Mimosæ* and other tropical products,—such as a mahogany log, found on Disco Island, which was

* Geographische Mittheilungen, 1854, p. 187.

made into a dining-table for the Governor of Holsteenborg. Moreover it has been noticed by several trustworthy observers, that icebergs often move *northwards* in Davis's Straits, in opposition to a *southerly* moving surface-current, as also against the wind. And although it might seem anomalous for a warmer stream to be flowing beneath a colder one, yet the anomaly disappears when we bear in mind that the surface-current, being composed in great degree of water which is the product of the liquefaction of icebergs, may have its salinity so reduced as to be specifically lighter than ordinary Oceanic water of higher temperature (§ 15). Although this warmer north-flowing body of water is assumed by Dr. Mühry to be a branch of the "Gulf-stream," there is a total absence of indication that it is derived from any other source than the general North-Atlantic area.

163. I come, lastly, to consider the question:—*Whether the North-easterly flow of relatively warm water, by which the Climate of the British Islands, and still more that of regions lying within the Arctic circle, is ameliorated, is attributable to the persistence of the initial force of the Gulf-stream proper, supplemented by the general Easterly surface-drift of the North Atlantic; or whether it is a larger and deeper movement, forming part of a General Oceanic Circulation sustained by difference of Temperature.*—As the direction of the Gulf-stream proper, where it is last to be recognized as a distinct Current, is nearly due East, and as the incidence of the Polar current off Newfoundland on its northern side will tend to give it rather a southward than a northward direction, the *sudden northward deflection* of the Isothermal lines on the eastern border of the Polar current, and their course of parallelism to the Greenland coast (which is as marked as the parallelism of the Gulf-stream to the coast of the United States as far north as Cape Hatteras), do not seem explicable on the idea of a *vis à tergo*; which must not only extend itself over the vast Oceanic area that intervenes between the eastern coast of Greenland and Scandinavia, but must change the direction of its operation without any assignable cause. Still less can it be shown, on this hypothesis, how a branch of the Gulf-stream should actually turn "round the corner" *westwards* into Baffin's Bay, so as to pass from W. Long. 50° to W. Long. 70°; and this notwithstanding its excess of *easterly* momentum, which would tend to carry any *north-moving* stream in the direction of Spitzbergen. Further, when we take account of the retardation which the Gulf-stream is known to undergo when flowing in the early part of its course as a compact and powerful current, it seems scarcely conceivable that it can long retain enough of its initial force to continue to make its way, when superficially extended over so vast a surface, against the retarding influence of the increased friction to which that extension must subject it with the watery bed over which it flows. And though it may be said, in answer to this objection, that its movement will be aided by the prevalent surface-drift, yet the influence of this can only extend to a very small depth; and the advocates of the "Gulf-stream" doctrine take

their stand upon its prolongation as a “*deep, warm, voluminous current.*” Under no other condition than this, indeed, can it retain its heat for any considerable duration, beneath an Atmosphere whose temperature is much below that of its surface (§ 155); for since, as we have seen (§ 142), the Gulf-stream, *even at its deepest and strongest*, loses in winter *fifteen degrees* of surface-heat while passing from the Florida Channel to the south of Nova Scotia, it must part much more rapidly with any excess it may still retain, when its superheated stratum has been thinned out by superficial extension, and when the progressive reduction of its movement to a rate *per day* not exceeding its rate *per hour* in the most rapid part of its course, prolongs its exposure from days to weeks, and from weeks to months.

164. I conclude, then, that *nothing save the general Northerly movement of a stratum of Water deep enough to retain an excess of heat through a lengthened period, whilst flowing beneath an Atmosphere of lower temperature than its own*, can account for the Thermal phenomena indicated in Dr. Petermann’s Gulf-stream Charts. Of such a movement it has been shown that the Temperature-soundings taken in the ‘Porcupine’ Expeditions afford very distinct evidence (§ 13). On the other hand, the very fact of its extension to so great a depth appears sufficient to negative the idea that it is to be accounted for either by the *vis à tergo* of the Florida current, or by the drift-action of S.W. winds on the surface.

II. ON THE DARDANELLES AND BALTIC UNDER-CURRENTS.

165. When discussing, in the Report of the ‘Porcupine’ Expedition for 1870, the Physical Theory of the Gibraltar Current, I endeavoured to strengthen my case by showing the applicability of that Theory, *mutatis mutandis*, to two other cases in which all the conditions of the Gibraltar Current are reversed together,—an Under-current of the heavy water of the German Ocean having been proved to flow inwards through the Baltic Sound, beneath the outward surface-current of lighter Baltic water; whilst the existence of a similar inflow from the Ægean into the Black Sea, beneath the outward surface-current of the Bosphorus and Dardanelles, might be predicated (I ventured to affirm, § 123) “on the double ground of *à priori* and *à posteriori* necessity.”—I much regret that I was not at that time acquainted with the experiments and observations which had been made by Capt. Spratt on the Dardanelles Current some years previously*; since, if they *had* fallen under my notice, I should have cited them as affording probative evidence of the truth of my position. For although the conclusion which Capt. Spratt has himself deduced from them is diametrically opposite to my own, yet the fallacy of that conclusion

* In excuse for my ignorance of Capt. Spratt’s inquiries on this subject, I may point out that the ‘Travels and Researches in Crete,’ in which they are published as an Appendix, is not a work into which any one seeking information upon the Dardanelles Current would naturally look.

appears to me so readily demonstrable, that I should have thought it sufficient to point out what I regard as the just interpretation of them, leaving it to the scientific public to decide whether his or my view of the case has the stronger claim to acceptance.

166. But as Capt. Spratt has made his experiments on the Dardanelles Current the basis of an assault*, not merely on the position I had ventured to assume (on theoretical grounds only) in regard to that current, but also on the Under-current doctrine which I had put forward as experimentally substantiated in the case of the Gibraltar and Baltic Currents, and, by implication, on the Doctrine of a General Oceanic Circulation which the inquiries I have recently had a share in conducting appear to me to justify, it is necessary for me to address myself to a more formal refutation of his arguments.

167. It may be thought presumptuous in one who can only claim to possess a merely elementary knowledge of Physical Science, and a very limited amount of practical acquaintance with inquiries of this nature, to call in question the unhesitating *dictum* of a Surveying Officer of Capt. Spratt's acknowledged ability and large experience, in regard to a matter lying completely within his own province. For however simple the case may *appear*, it might naturally be thought more probable that some essential condition had been left out of view on my part, than that Captain Spratt's interpretation of his results should be *precisely the reverse* of that which his own data necessitate. In order, therefore, to secure myself against any such error, I have submitted the case to several Naval Officers who have made a special study, both theoretically and practically, of all matters relating to Currents; and finding that their judgment entirely accords with my own, I venture to believe that the validity of my claim to a complete reversal of Capt. Spratt's conclusion will be generally admitted.

168. *Dardanelles Current*.—The method of experimenting adopted by Capt. Spratt was so nearly the same as that followed by Capt. Nares (under instructions from the Admiralty) in the experiments on the Gibraltar Current, of which the detail has already been given, that it is only requisite to recall its two essential features.—A float or buoy was attached to a sinker resting on the bottom, so as to serve as a fixed point of reference; this we shall call, as before, the *anchored buoy*. To another float or buoy, exactly resembling the first, was suspended at any desired depth a "current-drag," offering a large surface of resistance to any current in which it might hang; and the float which supports this we shall call (as before) the *current-buoy*.

169. Now I quite agree with Capt. Spratt, that if a surface-current flows past the "anchored buoy" and the "current-buoy" *at the same rate*, the current-drag suspended from the latter must be as motionless as the sinker to which the anchored buoy is attached; but I differ from him

* Proceedings of the Royal Society, vol. xix. p. 528 *et seq.*

in toto as to the cause of its stationary condition: for whilst *he* concludes that the current-drag remains stationary because it hangs in *perfectly still water*, it appears to me beyond question that it can only remain stationary whilst acted on by a *current flowing in the opposite direction*.

170. For let us consider (1) the condition of the "anchored buoy" lying in a surface-current that runs at the rate of (say) a mile per hour. The resistance offered to that current, not only by the buoy, but by the upper part of the anchoring line, puts that line on the stretch, so as to bring a very considerable strain alike on the buoy and on the sinker at the bottom.—In our own experiments in the Strait of Gibraltar, this strain was found to be so great, that a current of 1·25 mile per hour was sufficient to submerge a buoy capable of floating a weight of 100 lbs.; and when another buoy was attached to this, so as to keep it up to the surface, the strain of the current on the two proved so great as to lift and displace the sinker at the bottom, though it was a mass of iron weighing 1 cwt.—Let us suppose (2) the "current-drag" to be freely suspended in *perfectly-still water*, at any depth whatever above the bottom; it is obvious that, as the pressure of the surface-current upon its buoy and suspending line is precisely the same as in the preceding case, such pressure will put a strain upon the line, which will draw the "current-drag" along through the still water, in the direction of the surface-current, but at a reduced rate*; the flow of the current past the "current-buoy" being diminished by the amount of that motion.

171. Now if this be admitted, it necessarily follows (3) that if a "current-drag" suspended from a buoy floating in a surface-current remains motionless,—as shown by the equality of the rates of flow of the surface-current past the "current-buoy" and the "anchored buoy,"—the strain put upon its suspending line by the resistance of its current-buoy to the surface-current *must be neutralized by the pressure in an opposite direction of an Under-current meeting the "current-drag."*

172. And since, according to Capt. Spratt, this stationary condition of the "current-drag" was shown at all depths below 40 fathoms in the Sea of Marmora (even down to 400 fathoms), and at all depths below 20 fathoms in the Dardanelles, whilst there is a rapid superficial *out-current*, running in the Dardanelles at the rate of $2\frac{1}{4}$ miles per hour, it seems an irresistible conclusion that there is a deeper Under-current from 20 fathoms to the bottom, running more slowly *inwards* from the *Ægean* into the Sea of Marmora through the Dardanelles, and thence (it may be presumed) through the Bosphorus into the Black Sea. And this conclusion finds complete confirmation in the results of a comparison between the respective densities and rates of movement of the Dardanelles water at different depths, as observed by Capt. Spratt himself. For whilst the progressive

* It is not a little singular that Capt. Spratt admits this action (p. 535) in a case in which the "current-buoy" continued to move with the surface-current at the rate of 0·1 knot per hour; whilst refusing to admit it when the "current-buoy" was stationary.

decrease in the movement of the "current-buoy," from $2\frac{1}{4}$ knots at the surface to almost nothing at 20 fathoms, indicates (as just now shown) first a cessation of all movement in the stratum in which the "current-drag" hangs, and then a reversal in the direction of the current as the lower depth is approached,—the Specific Gravity was found to increase from 1020 at the surface to 1028 at 20 fathoms and 1029 at 40 fathoms; the surface-water thus corresponding with that of the Sea of Marmora, whilst the water of the entire stratum from 20 fathoms to the bottom was equal in density to that of the Mediterranean.

173. I hold, then, that the existence of an Under-current of dense Mediterranean water through the Dardanelles into the Sea of Marmora is incontestably proved by the very experiments and observations which have been adduced by Capt. Spratt as demonstrating the unsoundness of the Under-current doctrine*.

[ADDENDUM (Oct. 21, 1872).—Information has just reached this country, through the 'Levant Herald,' that the investigation of the Dardanelles Current made by the Surveying Staff of the 'Shearwater' since the above paragraphs were written on board her, has confirmed my original prediction, and entirely justified my interpretation of Captain Spratt's experiments. For, according to the statement of this journal (obviously made on authority), a boat was carried along by a "current-drag" suspended in the Under-current, *in opposition to the surface-current*, at a rate greater than the speed of the 'Shearwater's' steam-launch; and this under-current has been ascertained to run at a depth of 20 fathoms,—precisely that at which the results of Captain Spratt's experiments led me to predicate its existence.]

I venture to think that this complete verification of my prediction will be regarded as a confirmation of the general Physical Theory of Under-currents on which it was based: and it is now incumbent on those who oppose that Theory, to show by *what other force* than the difference in the weight of the Ægean and Black Sea columns, arising from their great difference in Specific Gravity, the Dardanelles Under-current can be sustained.

That a similar Under-current exists in the Bosphorus, has been (as I am assured by my friend Mr. Redhouse, who resided many years at Constantinople as Translator to the British Embassy) long known to the native

* It furnishes no argument against this conclusion, that (as stated by Capt. Spratt) during the winter months, when the Black-Sea rivers are at their lowest, a return *surface-current* is propelled into it by Westerly winds, *from the Ægean*, through the Dardanelles, Sea of Marmora, and Bosphorus. For the direction of the *surface-current* is entirely a question of Wind and of relative level; and the occasional reversal of that direction does not prove the non-existence of an inward *under-current* sustained by difference of vertical pressure. How a *surface* wind-current can bring into the Sea of Marmora the *deep* stratum of Ægean water which is proved by Captain Spratt's own Specific Gravity observations to overlies its bottom, he does not explain.

fishermen of Constantinople, as well as to European residents, who amuse themselves with the sport.

Further, I learn from a very careful observer, that at a time when the surface-current in the Dardanelles, urged by a S.W. wind, was setting *inwards*, as described by Captain Spratt, he noted that the *sub*-surface-movement, indicated by the direction of the water-weeds, was still *outwards*; thus showing how small must be the quantity of Ægean water carried into the Black Sea by this agency.]

174. *Gibraltar Current*.—As the experiments and observations of which I have given the details in the present Report furnish the best reply to Capt. Spratt's criticisms upon the work of the preceding year, I should have left those criticisms entirely unnoticed, were it not that one of them is founded upon a misconception of the facts of the case, which, in justice to my valued fellow-labourer Capt. Calver, I cannot leave uncorrected. It will be remembered that in two cases (Station 64) we actually *did* obtain the evidence, which, on Capt. Spratt's own admission, would be adequate (if valid) to establish the existence of an Under-current; namely, the movement of the boat from which the "current-drag" was suspended, in a direction *opposed* to that of the surface-current in which the boat was floating. So determined, however, is Capt. Spratt not to admit the cogency of this evidence, that, in order to invalidate it, he has recourse to the hypothesis that instead of the boat being carried along by the "current-drag," it was the "current-drag" that was carried along by the action of the wind and surface-current on the boat, which he supposes to have been allowed to drift "exposed nearly broadside on to an easterly wind, and therefore following swell." Now the fact was, that the boat was carefully kept by the two men in her with her stern to the wind; and that the "current-drag" (as was shown by the direction of the line suspending it from the bow of the boat) was always *in advance of it*; the action of the wind being so far from sufficient to neutralize that of the surface-current, that the men were obliged occasionally to use their oars to keep the boat sufficiently up to the drag. The whole operation was most carefully watched by Capt. Calver from the deck of the 'Porcupine,' which was kept close to the boat during the entire experiment; and as he assured me that he considered its result to be most conclusive, and as I reported that result expressly on his authority, I cannot but think that Capt. Spratt was scarcely justified in impugning the validity of the experiment, on no better grounds than a mere surmise suggested by his own unwillingness to accept its result.

175. *Baltic Current*.—While professing to disprove the conclusion drawn by Prof. Forchhammer from his observations on the relative Specific Gravities of the upper and under strata of the water in the Baltic Sound, Capt. Spratt altogether ignores the two facts by which the existence of an inward Under-current in that channel has been demonstrated with a com-

pleteness adequate (it might have been thought) to satisfy even his requirements. For it was stated two hundred years ago by Dr. Smith (who first advanced the hypothesis of the Gibraltar Under-current), on the authority of an intelligent Seaman who took part in the experiment, that a boat having been taken into the mid-stream of the Sound, where it was carried along violently by the outward current, a bucket was sunk with a heavy cannon-ball to a certain depth of water, which gave a check to the boat's motion; and that on sinking the bucket still lower, the boat was carried to windward against the upper current. The surface-current seemed to be not more than four or five fathoms deep; and the under-current was found to increase in strength, the lower the bucket was let fall*.—Again, it was stated by Prof. Forchhammer† that a steamer having been sunk, some years since, by a collision near Elsinore, a diver who went down to save the passengers' goods, found a strong Under-current running towards the Baltic.—Now since demonstrative evidence of the opposite movements of the upper and under strata, to which no exception has been taken by Captain Spratt, is here also in complete accordance with the inferences drawn from the contrast between their Specific Gravities, I must own myself unable to see by what right he excludes the case of the Baltic from the general Physical Theory which I have brought to bear upon it ‡.

176. But further, since the date of Capt. Spratt's communication, an important series of Researches on the Physics of the Baltic§ has been published by Dr. H. A. Meyer, who has been led, by his independent and long-continued inquiries, to feel assured of the existence of an inward under-current through the Baltic Sound, and who has been good enough further to inform me by letter that he has obtained additional evidence to the same effect of a still more satisfactory character. He quotes, also, the following observations made by Capt. Patton, R.N., in 1821 :—The ship which he commanded having had occasion to anchor some miles from Elsinore, he found a surface-current running from the Baltic at the rate of four miles an hour by the log. Upon dropping the lead, in order to ascertain the depth of water, which was about fourteen fathoms, he found the line continue perpendicular from his hand, while the lead itself was raised a little from the ground. Hence he concluded that an under-current equally rapid with that of the surface had prevented the lead

* Philosophical Transactions, vol. xix. p. 364.

† *Ibid.*, 1865, p. 230.

‡ Here, again, as in the case of the Black-Sea currents, Capt. Spratt considers it a sufficient disproof of the "Under-current Theory" to cite the fact mentioned by Prof. Forchhammer, that for 24 days out of 134 the *surface*-current runs *inwards* past Elsinore. This only shows that the level of the Baltic was then reduced, so that heavier water flowed back into it from the German Ocean; and does not in any way disprove the existence of an *inward* under-current when the surface-current is running *outwards*.

§ Untersuchungen über physikalische Verhältnisse des westlichen Theiles der Ost-See. Ein Beitrag zur Physik des Meeres, von Dr. H. A. Meyer, Kiel.

and line from yielding to the opposite motion of the fluid, as they would have done had the ship been sailing at that rate through the water*.

177. *General Oceanic Circulation.*—The animadversions which Capt. Spratt has made upon what he terms “the universal Under-current Theory so fascinatingly advocated by Maury and others, and more recently by the late Dr. Forchhammer,” have no real bearing upon the doctrine of a General Oceanic Circulation sustained by differences of Temperature alone, which I have recently been led to advocate. I do not in the least call in question the production of a *horizontal* circulation by Wind-currents; on the contrary, I have expressly pointed out, in the case of the Gulf-stream, what I believe to be the mode in which that circulation is completed: and I have no belief that, save under peculiarly exceptional conditions, any thing like a *current* can be produced by differences of Temperature alone. But to the question how the Temperature-phenomena which I have correlated are to be explained, except upon the supposition of a *continual movement* of Polar water, *however slow*, along the Ocean-bottom towards the Equator, involving as its necessary complement a flow of Equatorial water towards the Poles, Capt. Spratt does not seriously address himself; the Temperatures he cites being those collected in the older voyages, to which he has applied a correction of 4°, which is inadequate whenever it has reference to depths beneath 1200 fathoms. When the contrast I have drawn in the first part of my present Report between the Temperature-phenomena of Inland Seas,—such as the Mediterranean, the Red Sea, and the Sulu Sea,—with those of the Oceans with which they respectively communicate, shall have been rationally accounted for on *any other* hypothesis than that of a General Oceanic Circulation, the merits of the two explanations can be fairly discussed. But as such a discussion will be far more satisfactory when that vast mass of additional data shall have been collected which is likely to be furnished by the Scientific Expeditions that are at present either in progress or in preparation, I would suggest the expediency of postponing it until it can be more profitably resumed. At present, as I have already said, I claim for the doctrine of the General Oceanic Circulation no higher a character than that of “a good working hypothesis,” consistent with our present knowledge of facts, and therefore entitled to be *provisionally* adopted for the purpose of stimulating and directing further inquiry.

* Edinburgh Philosophical Journal, vol. iv. (1821), p. 245.

DIAGRAM I.
Comparison between Deep Temperatures of Open and of Land-locked Seas.

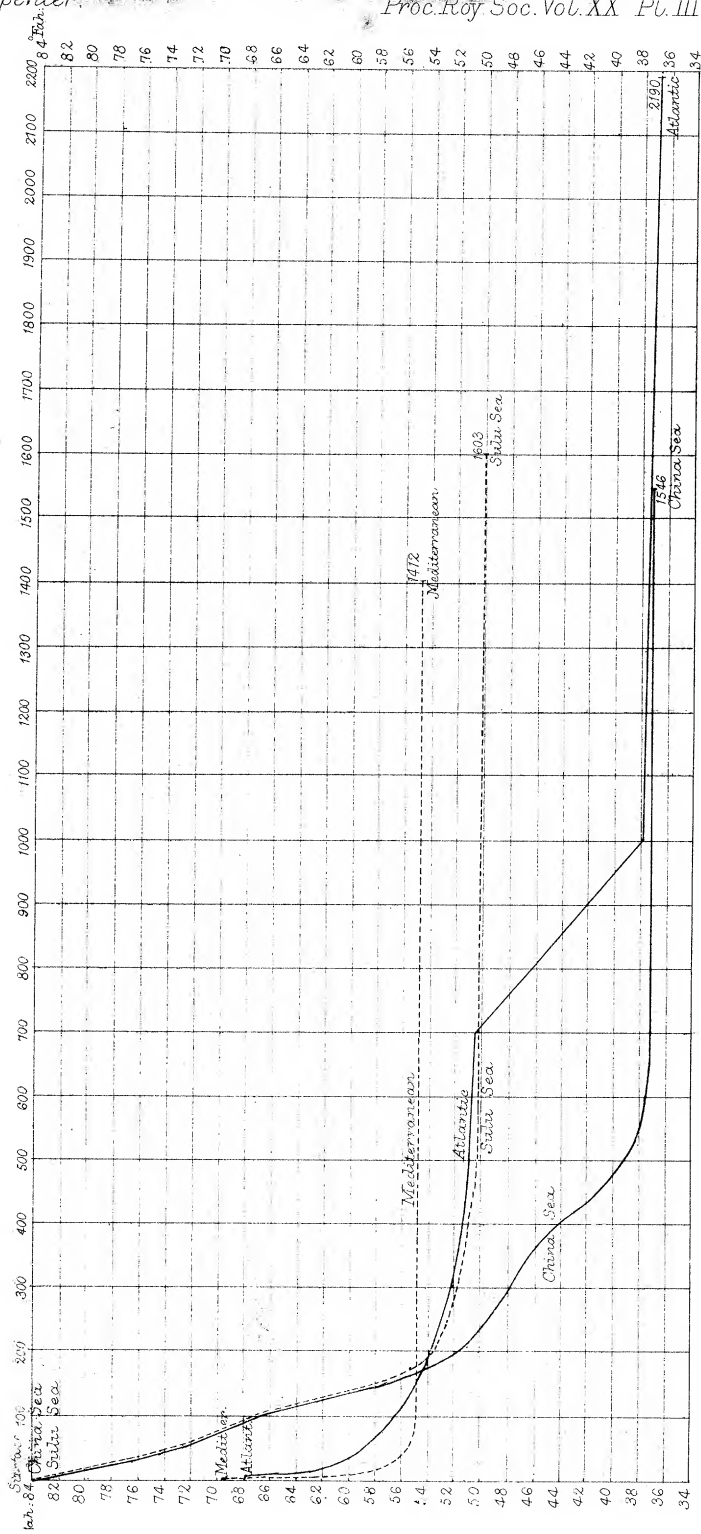


DIAGRAM II.

*Rate of Reduction of Temperature in Superficial Stratum
of Mediterranean.*

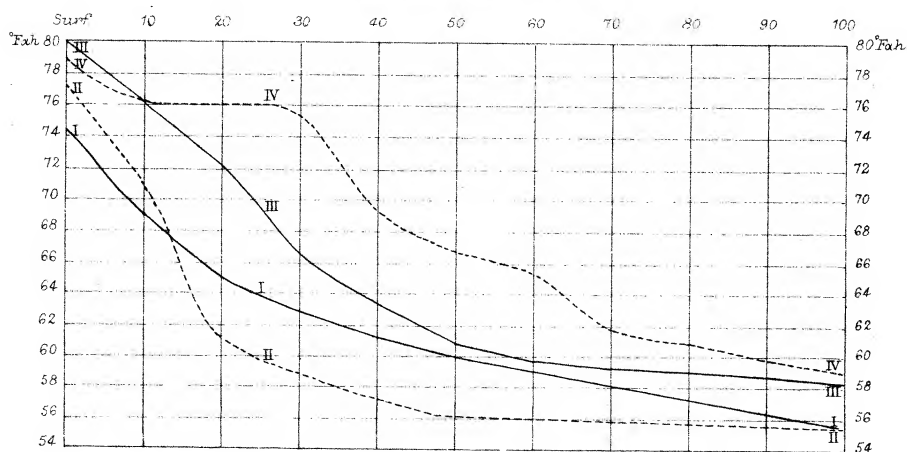


DIAGRAM III.

*Longitudinal Section in Course of Gulf Stream
showing Bathymetrical Isotherms.*

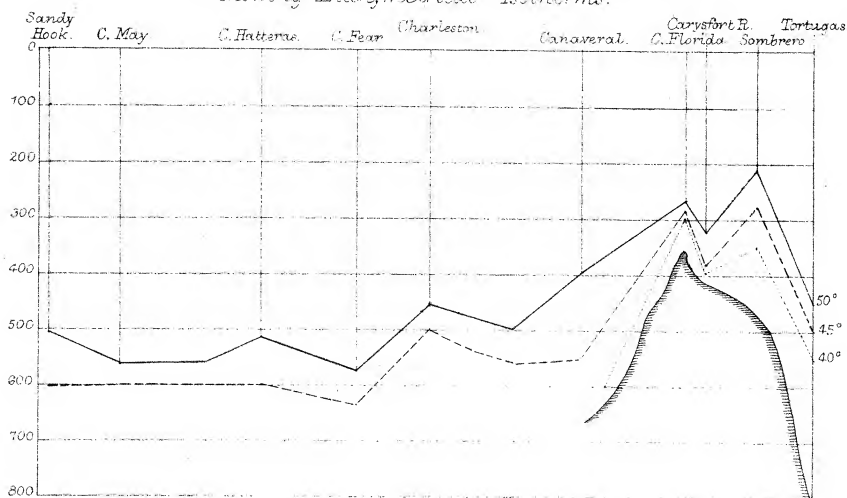


DIAGRAM IV.

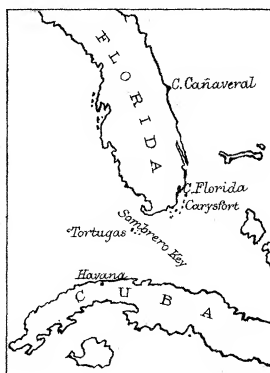
Map showing lines of Section
across Florida Channel.

DIAGRAM V.

Section off Sandy Hook.

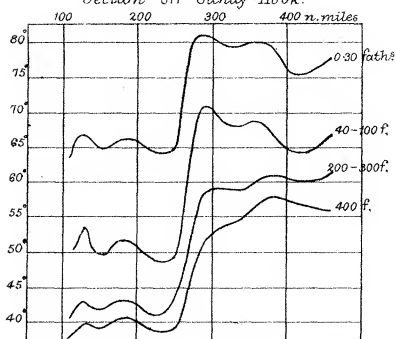


DIAGRAM VI.

Havana Section.

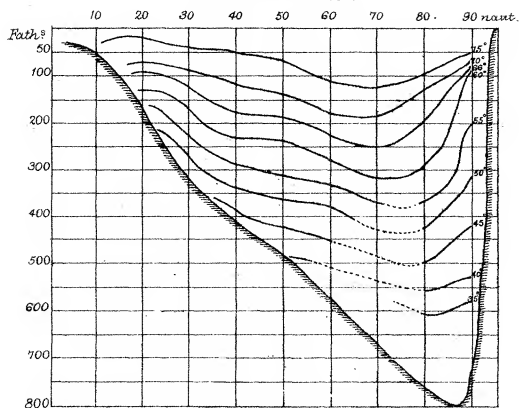


DIAGRAM VII.

Sombbrero Section.

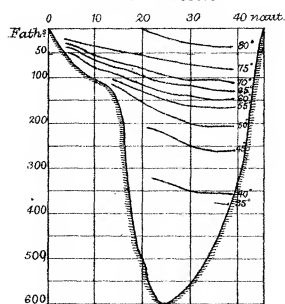


DIAGRAM VIII.

Carysfort Section.

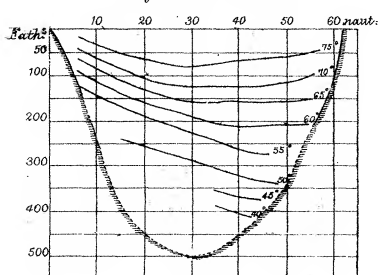
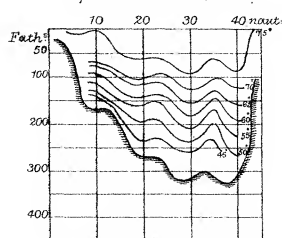


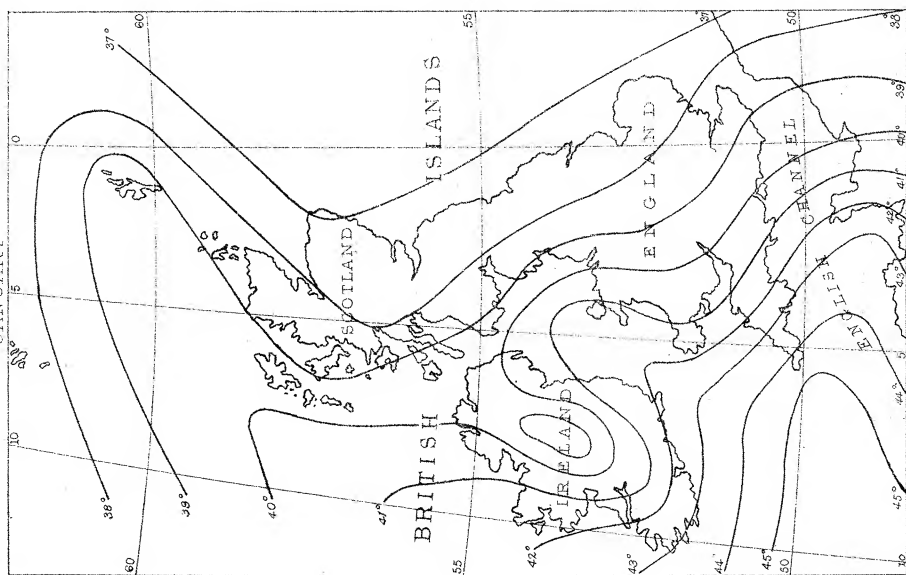
DIAGRAM IX.

Cape Florida Section.



ISOTHERMALS SHOWING THE MEAN TEMPERATURE OF THE BRITISH ISLES FOR JANUARY AND AUGUST
ON AN AVERAGE OF 13 YEARS ENDING 1869.

JANUARY



AUGUST.

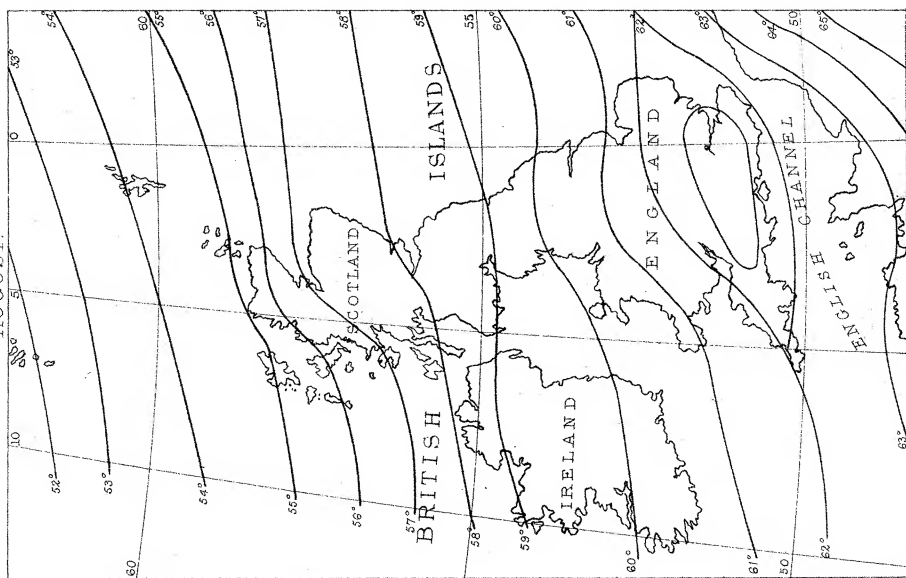


Chart of the Atlantic Ocean, showing its Isothermals
for January (continuous lines) and July (dotted lines)

